Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

Grant Agreement Nº: 101056730

Deliverable 3.4

Distributed Data Governance and Interoperability to Open-Source Energy Modelling Systems

Authors: Shahid Hussain and Fabiano Pallonetto
[National University of Ireland Maynooth (NUIM)]

Website FLOW

Funded by the European Union

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Document information Table

Project Data			
Project Acronym	FLOW		
Project Title	Flexible energy system Leveraging the Optimal integration of EVs deployment Wave		
Grant Agreement n.	101056730		
Topic identifier	HORIZON-CL5-2021-D5-01-03		
Funding Scheme	RIA		
Project duration	48 months		
Coordinator	Catalonia Institute for Energy Research		
Website	https://www.theflowproject.eu		
Deliverable Document Sheet			
Deliverable No.	3.1		
Deliverable title	Distributed Data Governance and Interoperability to Open-Source Energy Modelling Systems		
Description	A detailed report on the requirement analysis, design principles, and development of the FLOW E-mobility data space and governance framework		
WP No.	3		
Related task	3.4		
Lead beneficiary	NUIM		
Author(s)	Shahid Hussain and Fabiano Pallonetto		
Contributor(s)	NUIM		
Type	Report		
Dissemination L.	Public		
Due Date	30/04/2024	Submission Date	30/04/2024

Funded by the European Union

Version	Date	Author(s)	Organisation	Comments
V0.1	04/12/2023	Shahid Hussain and Fabiano Pallonetto	NUIM	The contents were discussed and the Initial layout for the document was created
V0.2	10/01/2024	Shahid Hussain and Fabiano Pallonetto	NUIM	Contents was created for the documents and literature survey was conducted
V0.5	15/02/2024	Shahid Hussain and Fabiano Pallonetto	NUIM	First draft of the document was developed and reviewed within the NUIM team
V0.6	15/03/2024	Shahid Hussain and Fabiano Pallonetto	NUIM	Document was modified following the comments and is sent for the FLOW internal review.
V0.9	10/04/2024	Shahid Hussain	NUIM	Modified according to the Fabiano Pallonetto (NUIM) and Alba Rodriguez Gonzalez (NUIM) comments.
V1.0	20/04/2024	Shahid Hussain	NUIM	Revised according to the FLOW internal review comments by Selene Liverani (E.DSO), De Michino Davide, ferdinando bosco (ENG).
V1.1	29/04/2024	Shahid Hussain	NUIM	Revised according to Pioppini Vittoria (Enel Group), Annigliato Costantino Marco, De Michino Davide (GLobal Mobility) Josh Eichman (IREC) and Sarah Cnockaert (IREC) comments.

Funded by the European Union

DISCLAIMER

Funded by
the European Union

Table of contents

1. Introduction 11
1.1. Enabler Level 11
1.2. Ground Level 13
1.3. Virtual Level 14
1.4. Stakeholder Level 15
1.5. Data Governance and EU Policy 16
1.5.1. The Need for Data Governance 16
1.5.2. Definition of the Data Governance 17
1.5.3. European Union Initiatives on Data Space 18
1.5.3.1. EU-Driven Strategic Coordination in Data Initiatives 19
1.5.3.2. Data for Energy 20
1.5.3.3. Sustainable Transport Forum 21
1.5.3.4. Data Space Support Centre 21
1.5.3.5. Mobility Data Space 22
2. Requirement Analysis of Data Governance for Energy Data Space 24
2.1. Importance of Data Governance in Energy Data Space 24
2.2. Types of Data Governance Approaches 25
2.2.1. Centralised Data Governance 26
2.2.2. Decentralised Data Governance 28
2.2.3. Hybrid Data Governance 30
2.3. Comparative Study of the Different Types of Data Governance Framework 33
2.4. Design Principle for the Data Governance Framework in the Energy Data Space 34
2.4.1. Conceptual Framework of Data Governance 34
2.4.2. Realisation of the Data Governance Framework 35
2.4.2.1. Data Interaction 35
2.4.2.2. Decision Dynamics 36
2.4.2.3. Key Dimensions 38
2.4.2.4. Process Optimisation 39
2.5. ISO/IEC 38505-1 based Data Governance Framework for Energy Data Space 39
2.5.1. ISO/IEC 38505-1 Accountability Map for Data Governance in Energy Data Space 40
3. Energy Data Space Framework and Their Data Governance 43
3.1. International Data Space Reference Architecture and Governance 43
3.2. Interoperable pan-European Grid Services Data Space Architecture 46
3.3. The EU-SysFlex Data Space Architecture and Governance 47
3.4. FlexiGrid Data Space Architecture and Governance 49
3.5. Platoon Energy System Data Space and Governance 50
3.5.1. Data Players 51

Funded by the European Union

3.5.2. Barriers in Data Exchange 52
3.5.3. Data Governance Recommendations 53
3.6. SYNERGY Data Space Architecture and Governance 54
3.7. OneNet Data Space Architecture and Governance 56
4. Semantic-Web based E-Mobility Data Space and Governance 58
4.1. Stakeholders in E-Mobility 58
4.1.1. Power Grid System 58
4.1.2. Transmission System Operators 59
4.1.3. Distribution System Operators 59
4.1.4. Utility company 60
4.1.5. Charging Station Operators 60
4.1.6. Charging Station 60
4.1.7. E-Mobility Service Providers 61
4.1.8. Fleet Operators 61
4.1.9. Energy Aggregators 61
4.1.10. Electric Vehicles 62
4.1.11. EV Owners 62
4.2. Characterisation of Stakeholders Data Types 63
4.3. Data Governance Dimensions in E-Mobility 64
4.3.1. Access Control Policy 64
4.3.2. Data Usage Policy 65
4.3.3. Data Retention Policy 65
4.3.4. Data Privacy Policy 66
4.3.5. Data Security Policy 66
4.3.6. Data Integrity Policy 66
4.4. Semantic-Web Ontology based Data Space and Governance for E-Mobility 70
4.4.1. Architecture of the Semantic-Web Ontology for E-Mobility Data Space and Governance 70
4.4.2. Purpose of E-Mobility Ontology 72
4.4.3. Scope of the E-Mobility Ontology 73
4.4.4. Competency Questions 73
4.4.5. Development of the E-Mobility Data Space and Governance Ontology 74
4.4.5.1. Classes in E-Mobility Data Space and Governance 75
4.4.5.2. Object Properties 78
4.4.5.3. Data Properties 79
4.4.5.4. Validation and Visualization 81
5. Conclusion 84
5.1. Contribution 84
5.2. Limitations 84

Funded by the European Union

5.3. Future Possible Direction 84
References 85

Funded by
the European Union

List of Acronyms

Acronym	Meaning
ABAC	Attribute-Based Access Control
ACL	Access Control List
ACP	Access Control Policy
AES	Advanced Encryption Standard
AFID	Alternative Fuels Infrastructure Directive
AMI	Advanced Metering Infrastructure
APIs	Application Programming Interfaces
BMDV	Federal Ministry of Digital Affairs and Transport
BOB	Best Operating Practices
BMS	Building Management System
CAAS	Connector-as-a-Service
CIM	Common Information Model
CSOs	Charging Station Operators
DEP	Data Exchange Platform
DERs	Distributed Energy Resources
DG	Data Governance
DEGs	Distributed Energy Generations
DLIES	Discrete Logarithm Integrated Encryption Scheme
DLS	Data Lineage Service
DPIA	Data Protection Impact Assessment
DRM	Datenraum Mobilität GmbH
DRMS	Demand Response Management System
DPP	Data Privacy Policy
DSO	Distribution System Operator
DH	Data Hub
DSF	Sustainable Transport Forum
DSSC	Data Spaces Support Centre
DUP	Data Usage Policy
ECIES	Elliptic Curve Integrated Encryption Scheme
EDC	Encrypted Data Connector
EG	Expert Group
EMSPs	E-Mobility Service Providers
ESOs	European Standards Organisations
EAX	Encrypt-then-Authenticate-and-Transmit
E-Mobility	Electric Mobility
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas Emissions
GPS	Global Positioning System
GCM	Galois/Counter Mode

Funded by the European Union

IEGSA	Interoperable pan-European Grid Services Architecture
IDS	International Data Spaces
IDS-RAM	IDS-Reference Architecture Model
IDSA	International Data Spaces Association
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JWT	JSON Web Tokens
KDF	Key Derivation Function
LEM	Local Energy Market
MC	Master Controller
MDS	Mobility Data Space
Mobilithek	Mobility Library
NGSI-LD	Next Generation Service Interface - Linked Data
PMU	Phase Measurement Unit
RACI	Responsible, Accountable, Consulted, and Informed
RBAC	Role-Based Access Control
RESs	Renewable Energy Sources
RSA	Rivest-Shamir-Adleman
SCADA	Supervisory Control and Data Acquisition
SGTF	Smart Grid Task Force
SHA	Secure Hash Algorithm
SPARQL	SPARQL Protocol and RDF Query Language
TLS	Transport Layer Security
TSOs	Transmission System Operators

Funded by the European Union

Executive Summary

The evolution of renewable energy sources is reshaping traditional power systems, transitioning from unidirectional to bidirectional flows of energy. This shift is fuelled by the integration of new stakeholders like prosumers, microgrids, energy aggregators, electric vehicle users, parking and charging station operators, and the evolution of the role of utility companies, and system operators. Together, they rely on various data types to optimise power system operations. A shared data space is crucial for seamless data exchange, particularly with the rise of new energy services in the digital energy market. This facilitates collaboration among suppliers and service providers, empowering them to innovate in the decentralised energy landscape. This deliverable presents energy data spaces and data governance from various perspectives. The aim of this deliverable is threefold:

1. In the decentralised energy landscape, systematically identify various stakeholders and delineate their roles in a layered approach, emphasising their interdependence on each other's data and underscoring the necessity for a data space. Conduct a comprehensive review of European Union policies and data governance regulations, with a specific emphasis on their strategic coordination in data initiatives within the energy and sustainable transport sectors to enhance understanding of the imperative role of the data governance framework in the evolving landscapes of energy and E-mobility.
2. Incorporating a comparative study among various data governance types to conduct a requirement analysis of data governance in the energy landscape. This includes highlighting the design principles for transforming a conceptual data governance framework into realisation, considering factors such as data interaction, decision dynamics, key dimensions, and process optimization. The analysis is guided by the ISO/IEC 38505-1 standardised data map-based Data Governance Framework. Following the requirement analysis, various EU data governance frameworks in the energy sector are reviewed from the perspective of requirements, aiming to understand the development of a data governance framework tailored for the E-mobility sector.
3. Identify stakeholders, delineate their data interactions, establish data governance policies, and formulate a semantic-web ontology for E-mobility. Construct a robust data governance architecture, and conduct a comprehensive requirement analysis, emphasising the ontology's purpose, scope, and competency questions. Finally, validate and visualise the developed ontology using DL queries.

This document establishes the groundwork for an open data space and data governance framework, outlining essential requirements, design principles, and reviewing existing data space and data governance models in the energy landscape. It aims to contribute to the development of an open data space and data governance framework tailored for the E-mobility sector. However, However, it acknowledges the imperative for further investigations and laboratory tests to ensure the development of a robust, interoperable framework that encompasses both electric and mobility features. This framework should align seamlessly with EU policies, supporting the requirements of both mobility and energy systems.

Funded by the European Union

1. Introduction

The traditional power grid, conceived decades ago, was designed to facilitate electricity distribution from centralised power generation plants. It relied on a high-voltage transmission network covering substantial distances to deliver power to end-users through a low-voltage distribution network, offering limited flexibility [1]. Electricity demand has increased and will continue increasing [2]. At the same time, traditional electricity generation based on fossil fuels should be phased out to decrease GHG emissions and reach Green Deal/net-zero objectives [3]. To accommodate more RES (clean energy generation), facilitate decentralisation of the power system, allow grid expansion (necessary to face the increase in electrification), etc. modernisation is needed [4]. This transition entails moving from traditional unidirectional power systems to smart power systems by seamlessly integrating solar panels, battery storage, heat pumps, boilers, and electric vehicles into existing electricity networks. This trend has led to a significant rise in smaller-scale generation plants directly connected to consumer-end terminals, exemplifying the concept of small-scale prosumers engaged in distributed energy generation (DEG). The worldwide shift towards distributed generation is facilitated by advancements in technology and shifts in the economic and environmental landscapes. The primary factors of this shift, as highlighted by the authors in [5], include:

- Concerns regarding the initial setup costs of centralised power plant systems and associated environmental considerations.
- The ageing infrastructure, wear and tear, and capacity limitations of the transmission and distribution lines that facilitate the distribution of bulk power.
- The rise in economic viability of large-scale manufacturing of smaller devices compared to the heavy manufacturing of larger units and on-site construction.

The integration of distributed energy generations (DEGs) results in a decentralised power system, with numerous DEGs utilising a variety of technologies including small gas turbines, micro-turbines, power devices, wind and solar energy, biomass, and more, as shown in Figure 1 [5]. These technologies are deployed to address the energy demand of local consumers and transition them from traditional consumers to prosumers. This transformation allows individuals or entities to not only consume energy but also actively contribute to renewable electricity generation and grid stability. This shift is particularly valuable in scenarios where establishing central power generation is impractical or transmitting power to remote areas presents challenges. The transition from the conventional power system to the smart grid has fostered collaboration among a range of stakeholders, organised into four distinct levels, as illustrated in Figure 2 [6]. Subsequently, the presentation outlines these levels, detailing the corresponding functional entities and the data they utilise within each level, as given below.

1.1. Enabler Level

The enabler level, encompassing policy and regulation, serves as a pivotal cornerstone in shaping the energy landscape, providing a structured framework for the development, deployment, and management of energy resources [7]. These measures are strategically developed to achieve diverse objectives, including advancing sustainability, ensuring reliability, fostering healthy

Funded by the European Union

competition, and mitigating environmental concerns. The various entities engaged at the enabler level are delineated in the subsequent discussion.

- **Government Agencies:** Government agencies formulate and implement energy policies, set regulatory frameworks, and oversee compliance. They play a central role in strategic planning, infrastructure development, and ensuring national energy security. They collect and analyse data related to national energy consumption, production, and trends. To establish their objectives, they need different data including information on existing infrastructure, energy imports and exports, and the overall energy landscape.
- **National Regulatory Authorities:** National regulatory authorise (NRAs) set utility rates, approve infrastructure investments, and ensure fair market practices. They act as watchdogs, balancing the interests of consumers and utilities while enforcing compliance with regulations and therefore, they gather data on utility performance, consumer complaints, and market dynamics. Moreover, they also assess financial reports and operational metrics submitted by utilities.
- **Utilities and Energy Companies:** Utility companies invest in infrastructure, ensuring grid reliability and security of supply, and delivering energy services to consumers, thus serving the entire spectrum from production to consumption. They also actively participate in regulatory processes by collecting real-time grid data, maintenance records, and consumer usage patterns to facilitate reliable transmission and distribution. In doing so, they provide valuable input for policy formulation.
- **Environmental Organisations:** Environmental organisations play a vital role in influencing policy decisions to promote cleaner energy and mitigate environmental impacts. Their functions include advocating for sustainable practices, monitoring compliance with environmental regulations, and engaging in public awareness campaigns. They collect data on air and water quality, biodiversity, and the environmental impact of energy-related activities.

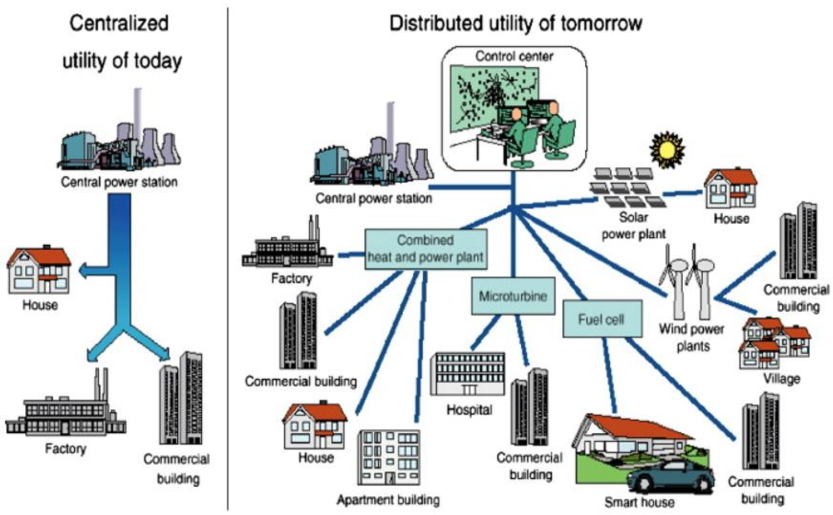

Figure 1. A representation of the power system transition from centralised generation to decentralised generation highlighting several functional entities [5].

1.2. Ground Level

The ground level in the energy system refers to the foundational elements that directly impact energy production and economic considerations [8]. The four key components involved at the ground level are Power Plants, Grid, Economic Incentives, and Targeted Best Operating Practices (BOB) [9]. These interconnected components work collaboratively to ensure a reliable, efficient, and sustainable energy system. Power plants act as core producers, the grid facilitates seamless energy distribution, economic incentives guide investment decisions, and targeted BOB ensures optimal operations in alignment with industry standards and environmental considerations. The effectiveness of policies and practices at the ground level significantly influences the broader energy landscape.

- **Power Plant:** Power plants are the primary entities responsible for generating electricity. They convert various energy sources, such as fossil fuels, renewables, or nuclear energy, into electrical power. The functions include continuous monitoring, maintenance, and adherence to safety and environmental standards. They utilise extensive data related to electricity production, including output capacity, efficiency, fuel consumption, and maintenance records. This information is crucial for monitoring plant performance and optimising energy production.
- **Power Grid:** The grid serves as the backbone of the energy system, facilitating the transmission and distribution of electricity from power plants to end-users. Its functions include managing the flow of electricity, integrating renewable energy sources, and ensuring reliability of supply to grid users. The grid collects data on electricity demand, transmission efficiency, and real-time system conditions, which is crucial for grid operators to balance supply and demand and ensure grid stability.
- **Economic Incentives:** Economic incentives play a vital role in shaping the energy landscape. Mostly, the governments and regulatory bodies use financial mechanisms to encourage investment in sustainable and efficient energy practices. This can include tax credits for renewable projects or subsidies to promote the adoption of cleaner technologies. To facilitate financial benefits, they require data related to financial structures, subsidies, tax credits, and investment patterns. Moreover, this also includes information on government incentives for renewable energy projects and market mechanisms influencing energy prices.
- **Targeted Best Operation Practices:** Targeted BOB refers to the implementation of industry best practices to enhance the efficiency, reliability, and safety of energy operations. This includes adopting cutting-edge technologies, optimising maintenance schedules, and ensuring compliance with environmental regulations. Best Operating Practices involve data on efficient and effective operational strategies, including maintenance schedules, technological advancements, and safety protocols. This data ensures optimal performance and adherence to industry standards.

Funded by the European Union

1.3. Virtual Level

The virtual level in the energy system represents an advanced layer of technologies and systems that leverage digital capabilities to enhance energy efficiency, flexibility, and user engagement [10]. These technologies empower consumers with greater control over their energy usage, facilitate decentralised energy markets, and seamlessly integrate demand response strategies into best operating practices. The virtual level plays a critical role in enhancing the overall resilience and sustainability of the energy ecosystem. Key components constituting the virtual level include the Demand Response Management System (DRMS), Building Management System (BMS), Local Energy Market (LEM), Consumer Portal, and Integrated Demand Response for Best Operating Practices (BOB) [11].

- **Demand Response Management System:** The demand response management system (DRMS) enables the dynamic adjustment of energy consumption in response to grid conditions or price signals. It optimises demand response strategies, coordinating actions to reduce or shift energy usage during peak periods or in response to grid constraints. DRMS collects and analyses real-time data on energy consumption patterns, grid conditions, and external factors influencing energy demand. This includes information from smart metres and sensors.
- **Building Management System:** The building management system (BMS) optimises building operations by controlling heating, ventilation, and air conditioning (HVAC) systems, lighting, and other energy-consuming devices based on real-time data. It enhances energy efficiency, occupant comfort, and overall building performance. BMS collects data from various sensors within buildings, monitoring parameters such as temperature, occupancy, and energy usage and integrates with optimization algorithms for a holistic view of building performance.
- **Local Energy Market:** The local energy market (LEM) provides a platform for localised energy transactions, allowing consumers to buy and sell energy within their community. It promotes the use of renewable energy sources and facilitates decentralised energy trading. The LEM gathers data on local energy supply and demand, including information on available renewable energy, local grid conditions, storage capacity, and consumer preferences.
- **Consumer Portal:** The consumer portal engages energy users by offering insights into their energy usage, facilitating participation in demand response programs, and providing a user-friendly interface for energy-related decision-making. The consumer portal aggregates and presents data on individual energy consumption, costs, and available incentives. It may also provide real-time information on grid conditions and personalised energy-saving tips.
- **Integrated Demand Response for Best Operating Practices:** This system ensures that demand response actions align with the best operating practices of the entire energy system. It optimises energy consumption patterns based on real-time data, grid conditions, and the specific operational requirements of the entire energy ecosystem.

Funded by the European Union

Integrated Demand Response for BOB involves the integration of data from various sources, including DRMS, BMS, and LEM, to optimise energy demand response strategies in alignment with best operating practices.

1.4. Stakeholder Level

The stakeholder level is characterised by collaboration and interaction among entities, each contributing to the overall efficiency, resilience, and sustainability of the energy system [12]. Key stakeholders at this level include Transmission System Operators (TSO), Distribution System Operators (DSO), Retailers (Utility Companies), Consumers (Households, Electric Vehicles (EVs)), Building Managers, and Market Maintenance Operators for LEM [6, 13]. Coordination among TSOs, DSOs, retailers, consumers, building managers, and maintenance operators is essential for achieving a well-functioning and responsive energy ecosystem.

- **Transmission System Operators:** The transmission system operators (TSOs) are responsible for the high-voltage transmission of electricity over long distances. They ensure grid reliability, manage system constraints, and coordinate with other TSOs for cross-border electricity exchange. TSOs collect and analyse data on electricity transmission, grid stability, and overall system conditions. This includes information on power flows, grid congestion, and interconnection with neighbouring systems.
- **Distribution System Operators:** The distribution system operators (DSOs) manage the distribution of electricity to end-users within their designated areas. They maintain local grid stability, facilitate the connection of new distributed generation sources, and handle grid congestion issues. DSOs gather data on electricity distribution within specific regions that are related to the local grid conditions, load profiles, and the integration of distributed energy resources (DERs).
- **Retailers:** The retailers or the utility companies interact directly with consumers, providing energy services, billing, and customer support. They also play a role in shaping market dynamics, offering various pricing plans, and promoting energy efficiency programs. Retailers collect data on consumer energy usage, billing information, and market trends. This includes data on tariff structures, customer preferences, and demand patterns.
- **Consumers:** The consumers play a pivotal role in the energy system by determining overall demand patterns. They may engage in demand response programs, adopt energy-efficient practices, and, in the case of EVs, contribute to the evolution of smart charging solutions. Consumers contribute data on individual energy usage patterns, preferences, and demand response participation. This may include information from smart metres, EV charging stations, and home energy management systems.
- **Building Managers:** The building managers optimise the energy performance of structures by controlling HVAC systems, lighting, and other building systems. They ensure efficient operations, occupant comfort, and adherence to energy efficiency goals. Building managers collect data from BMS, including occupancy patterns, energy

Funded by the European Union

consumption, and maintenance needs. They may also integrate data from other building systems for comprehensive management.

- **Maintenance Operators:** Maintenance operators play a crucial role in ensuring the reliability and optimal performance of assets within local energy markets. They conduct routine maintenance, address issues promptly, and contribute to the overall stability of the local energy ecosystem. Maintenance operators within LEM gather data on the performance of local energy assets, including renewable energy systems, storage, and demand response capabilities.

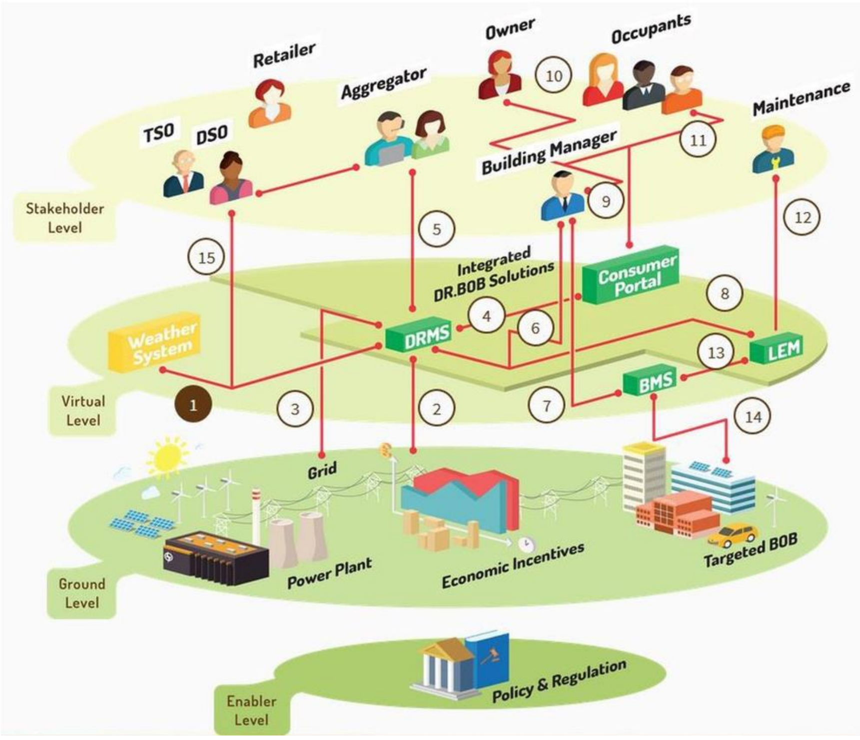

Figure 2. An overview of the different stakeholders in the EV ecosystem and their interaction through various protocols (Source: IEA CC BY 4.0) [6].

1.5. Data Governance and EU Policy

In the progression from a centralised to a decentralised power system, involving the array of stakeholders discussed earlier, this section accentuates the crucial need for data governance. It elucidates the concept of data governance in detail and examines European Union policies that explicitly underscore the importance of both data governance and interoperability.

1.5.1. The Need for Data Governance

The preceding discussion illustrates the involvement of various entities and their operations. Efficient data management within the complex energy flows heavily relies on real-time digitised data exchange across diverse domains such as mobility, buildings, retail, energy, and industry [14]. This digitised data exchange plays a pivotal role in enabling an advanced energy system,

Funded by the European Union

significantly enhancing processes. It facilitates faster, automated, and precise planning, thereby improving our ability to anticipate energy-related processes. However, these cross-stakeholder relationships are interdependent on various types of data, necessitating a framework that focuses on distributed data governance and interoperability for open-source energy modelling systems. Consequently, in this deliverable, we present different frameworks on distributed data governance and interoperability. We highlight key challenges and provide recommendations for a standardised framework following the EU General Data Protection Regulation (GDPR) to ensure security, interoperability, reutilisation, and support for the overall energy landscape.

1.5.2. Definition of the Data Governance

The progression of renewable energy technologies, the emergence of flexibility services, demand-side management, and the broader focus on energy efficiency underscore the imperative for harmonisation across sectors. This necessitates the seamless exchange of diverse data among key stakeholders, encompassing the power grid, TSOs, DSOs, utility companies, energy aggregators, buildings, residences, charging station operators, and electric vehicle owners. This signifies that open access to data and its exchange not only enhances efficiency gains in power grid operations and planning but also reduces barriers to market access. It ensures transparency in consumer usage and contributes to the development of new market opportunities and business models [15]. Consequently, a robust data governance framework is essential to support these advancements. Several definitions of data governance exist in the literature. For instance, some definitions of Data Governance provided in the literature are:

Definition 1: It is described as the amalgamation of decision rights, processes, standards, policies, and technologies essential for the management, maintenance, and optimal utilisation of information as a strategic enterprise resource [16].

Definition 2: Data governance is articulated as the practice of structuring and implementing policies, procedures, and standards to facilitate the effective utilisation of an organisation's structured and unstructured information assets [17].

Definition 3: Data Governance is characterised as a systematic framework comprising decision rights and accountabilities for information-related processes. It is executed based on agreed-upon models that delineate who can undertake specific actions with information, when, under what circumstances, and using what methods [18].

Nevertheless, the definitions provided thus far primarily focus on data governance from a general perspective, lacking a dedicated overview of distributed data governance within the energy landscape. To address this gap, we combine these perspectives to define distributed data governance in an energy system. It is characterised as the systematic management, control, and oversight of data across decentralised stakeholders participating in the energy landscape. This definition stems from the imperative to establish robust policies, processes, and frameworks, ensuring the quality, security, privacy, and interoperability of data within the intricate network of nodes, devices, and stakeholders in the energy ecosystem. This comprehensive definition serves as a guiding framework for navigating the intricate terrain of data governance in the dynamic field of energy management. Key components of distributed data governance in an energy system include:

Funded by
the European Union

1. **Data Quality Assurance:** Ensuring that data is accurate, reliable, and consistent across all distributed sources and applications within the energy system.
2. **Security Measures:** Implementing robust security protocols to protect data from unauthorised access, cyber threats, and breaches, especially in a distributed environment.
3. **Privacy Considerations:** Adhering to privacy regulations and standards to protect sensitive information, particularly as data is exchanged among various entities.
4. **Interoperability Standards:** Establishing common data standards and formats to facilitate seamless communication and exchange of information between decentralised components.
5. **Data Lifecycle Management:** Managing the entire lifecycle of data, from creation and collection to storage, analysis, and eventual disposal, ensuring efficient and responsible data handling.
6. **Compliance with Regulations:** Adhering to relevant regulations and compliance standards, such as those set forth by government bodies or industry-specific authorities.
7. **Collaborative Governance:** Fostering collaboration among diverse stakeholders to collectively contribute to the governance of distributed data, promoting transparency and accountability.

1.5.3. European Union Initiatives on Data Space

To mitigate the European Union's reliance on fossil fuels, address the climate crisis, and ensure equitable access to affordable energy, the EU's European Green Deal is committed to establishing an interactive and intelligent energy system [19]. Achieving energy and resource efficiency, decarbonization, electrification, sector integration, and decentralisation necessitate a significant emphasis on digitalization. The Digital Decade Policy Programme 2030, aligned with the European Green Deal, prioritises the digital transformation of the energy system, as through digital tools, room temperatures can be automatically regulated, electric cars efficiently charged, and appliances managed to optimise energy consumption at the most cost-effective rates, all while maintaining a comfortable and healthy indoor environment [20]. Furthermore, these digital tools empower public authorities to effectively map, monitor, and address energy poverty, while offering the energy sector enhanced capabilities to optimise operations and prioritise the utilisation of renewable energy sources. The evolution of sensing technology has significantly impacted the energy sector, particularly in areas such as electric vehicles, charging stations, renewable energy, heat pumps, and home energy management systems. These advancements in technology have equipped these sectors with smart capabilities, enabling the generation of data and facilitating remote monitoring and control functionalities. The digital and energy policies established by the EU are currently pivotal in steering the digitisation of the energy sector. The current regulatory framework in Europe for energy has set the foundation, and the proposed Data Act [21] introduces new regulations regarding the utilisation and access of data generated within the EU across various sectors. It explicitly outlines users' rights to freely access and use the data produced by their products, encompassing the right to share such data with third parties. Furthermore, the Data Governance Act [22] is designed to enhance data sharing mechanisms and build trust in data intermediaries, with the objective of promoting data availability. The

Funded by the European Union

fundamental prerequisite of the data space framework is to ensure the accessibility, availability, and secure sharing of energy-related data through seamless transfers among trusted parties [23]. To operationalize this legislative mandate and facilitate effective and efficient data exchanges, the EU framework delineates a coordinated approach [24], as outlined below.

1.5.3.1. EU-Driven Strategic Coordination in Data Initiatives

The European Commission has initiated the Smart Grid Task Force (SGTF) in January 2009 to advance the digitalisation of the energy sector by formulating policy and regulatory frameworks for the implementation of smart grids across Europe [25]. The SGTF comprises five Expert Groups (EGs) with distinct focuses: EG1 concentrates on defining smart grid standards, EG2 addresses regulatory recommendations concerning privacy, data protection, and cybersecurity within the smart grid environment; EG3 provides regulatory recommendations for the deployment of smart grids; EG4 focuses on the deployment of smart grid infrastructure; and, finally, EG5 is dedicated to the industrial aspects of smart grids. This collaborative framework aims to guide and promote the development of smart grids while addressing key regulatory, privacy, and infrastructure considerations. In the domain of data governance, the SGTF prioritises two key aspects essential for preparing smart grid infrastructure.

- **Data protection and security:** Data protection and security considerations encompass the securing of personal data through the adoption of '*data protection by design*' and '*data protection by default settings*' measures. The former entails integrating data protection security into products and services right from the initial stages of development. This should be implemented legislatively, ensuring compliance with data protection laws. On a technical level, it involves setting appropriate requirements in smart grid standards to ensure full alignment with data protection laws. Additionally, at the organisational level, it pertains to processing procedures. Meanwhile, the later entails offering the most data-protection-friendly option to customers as the default configuration. This approach seeks to prioritise privacy and security in the default settings provided to users.
- **Data protection impact assessment template:** The development of a 'Data Protection Impact Assessment Template (DPIA)' serves the primary purpose of providing thorough guidance to data controllers for conducting a tailored data protection impact assessment specifically designed for smart grid and smart metering systems. The guidance provided by the DPIA template encompasses several key elements:
    - **Scope Definition:** Clearly defining the scope of the smart grid or smart metering system project, including the extent of data processing activities involved.
    - **Data Processing Description:** Offering a detailed overview of the data processing operations within the smart grid or smart metering context, identifying the types of data collected, processed, and stored.
    - **Identification of Risks:** Systematically identifying and evaluating potential risks to data protection associated with the smart grid or smart metering project. This

Funded by the European Union

includes considering factors such as data breaches, unauthorised access, or other privacy-related concerns.

- **Legal and Regulatory Compliance:** Ensuring alignment with legal and regulatory requirements, particularly those related to data protection laws. This involves assessing the project's conformity with existing regulations and guidelines.
- **Mitigation Measures:** Recommending and outlining measures to mitigate identified risks, enhancing the overall data protection posture of the smart grid or smart metering system. This may include encryption protocols, access controls, or other security measures.
- **Stakeholder Involvement:** Encouraging active involvement and collaboration with relevant stakeholders, including data subjects, throughout the assessment process to incorporate diverse perspectives and concerns.
- **Documentation:** Emphasising the importance of thorough documentation of the entire data protection impact assessment process, including the rationale behind decisions, identified risks, and implemented mitigation strategies.

1.5.3.2. Data for Energy

Specifically related to energy data, the Commission has expanded the scope of the SGTF by introducing the 'Data for Energy' (D4E) working group in the first quarter of 2023 [26]. This group is dedicated to bringing together the Commission, Member States, and relevant public and private stakeholders to contribute to the establishment of a European framework for sharing energy-related data. The primary focus of D4E is to enhance coordination at the EU level concerning data exchanges in the energy sector. This involves defining key principles and ensuring consistency across various data-sharing priorities and initiatives. Moreover, D4E plays a crucial role in supporting the Commission in the formulation and implementation of a common European data space for energy. In this collaborative effort, the governance structure and foundational elements of the impending data space will be strategically designed and jointly managed. This collaborative approach emphasises partnership and coordination among key stakeholders to foster a cohesive and effective framework for sharing energy-related data within the European Union. The high-level use cases outlined in D4E encompass a range of applications, including flexibility services within energy markets and grids, smart and bi-directional charging for electric vehicles, and the development of smart and energy-efficient buildings. This initiative also aims to boost both private and public investments while leveraging the proposed solar rooftop initiative [27]. Among these use cases, D4E's objective is to establish priority areas by providing detailed implementation plans and deliverables, acting as foundational building blocks for the future European energy data space. Additionally, D4E places significant emphasis on close collaboration with the Expert Group on the European financial data space. This collaboration aims to identify use cases of common interest, directing private financial resources towards facilitating the energy transition. The overarching goal of D4E is to coordinate closely with the European Data Innovation Board and emerging governance structures of other European data spaces. This coordination is essential to establish consistent approaches and embed interoperable processes from the outset, thereby assisting the European Commission in implementing governance for the

Funded by the European Union

common European data space for energy. These proposals will be presented to the Commission for endorsement and subsequent action.

1.5.3.3. Sustainable Transport Forum

Recognising the pivotal role of EVs as a sustainable alternative in the energy landscape, the Commission has delineated a collaborative work program for both D4E and the Sustainable Transport Forum [28]. This collaborative effort seeks to ensure alignment between energy and mobility data spaces, fostering system integration and offering cross-sectoral services. These sectors encompass various stakeholders, including the environment, mobility, consumers, prosumers, civil society, manufacturers of alternative fuel vehicles, relevant transport operators and users, operators and users of alternative fuel infrastructure, mobility services providers, academia, and standardisation bodies. The program is specifically oriented toward the advancement of intelligent and bi-directional EV charging solutions, integrating technologies to optimise the efficiency and functionality of electric vehicle charging systems. The STF was established to support the Commission in key tasks related to implementing the Union's initiatives and programs aimed at promoting the deployment of alternative fuels infrastructure, contributing to the European Union's energy and climate objectives. Specifically, the SFT aims to:

- Assist the Commission in formulating policy initiatives in the realm of sustainable mobility, including EVs, hydrogen fuel EVs, and alternative transport fuels and infrastructure policy.
- Aid the Commission in developing delegated acts under Directive 2014/94/EU, the Alternative Fuels Infrastructure Directive (AFID), which seeks to establish a more sustainable and integrated transportation system by promoting the use of alternative electricity, hydrogen, and natural gas fuels.
- Facilitate cooperation and coordination between the Commission and Member States or stakeholders concerning the implementation of Union legislation, programs, and policies related to alternative transport fuels and infrastructure policy.
- Foster an exchange of experiences and best practices in the field of alternative transport fuels and infrastructure.

1.5.3.4. Data Space Support Centre

The Data Spaces Support Centre (DSSC) [29] stands as an integral initiative under the European Commission's Digital Europe Program, strategically unifying a multidisciplinary consortium of knowledge centres specialised in data spaces. This consortium boasts a diverse membership, an extensive network, national hubs, open-source communities, and pioneers in the field of data spaces. The initiative aims to identify and standardise technologies and tools that facilitate the use and sharing of data across sectors, emphasising considerations for security, access procedures, and alignment with sector-specific standardisation activities. Additionally, the focus extends to creating conditions for an open data ecosystem characterised by interoperability and mutual trust. This involves defining common building blocks for business, legal, operational, technical, and societal aspects. The key objectives of the DSSC are as follows.

Funded by the European Union

- **Availability of Technologies and Frameworks:** Enable the availability of technologies, processes, legal frameworks, standards, and tools (such as the Community of Practice and Blueprint) for the deployment of data spaces.
- **Adoption of Technologies and Standards:** Foster the adoption of identified technologies and standards to enable the reuse of data across sectors, promoting a multidisciplinary approach based on co-creation and interaction.
- **Sustainable Products and Services:** Contribute to the generation of sustainable and scalable products and services for the global market by leveraging shared data in business model development and facilitating efficient, effective, and repeatable policy decision-making.
- **Controlled Data Availability:** Ensure that more data becomes available for use in the economy and society while keeping those who generate the data in control.
- **Facilitate Data Sharing:** Facilitate the sharing of data, creating a positive impact in the daily lives of citizens and instilling confidence in businesses and public administrations.

The overarching goal is to facilitate seamless data flows within the energy data space, promoting cross-sectoral interoperability in alignment with upcoming Commission requirements. The initiative also aims to provide guidance to emerging sectoral data spaces, aiding in their establishment by delivering relevant technologies, processes, and tools.

1.5.3.5. Mobility Data Space

The Mobility Data Space (MDS) [30] is a project funded by the Federal Ministry of Digital Affairs and Transport (BMDV) with the primary objective of enhancing mobility by promoting safety, efficiency, and environmental friendliness. Positioned as a neutral and trustworthy entity, the MDS serves as the foundation for establishing a connected and secure data infrastructure in Europe. The initiative aligns with European values, prioritising aspects such as data protection, data sovereignty, and interoperability. The non-profit organisation overseeing the Mobility Data Space is DRM Datenraum Mobilität GmbH, an entity originating from a project initiated by the acatech Foundation. The key characteristics of the MDS are discussed as follows.

- **Data Protection Approach:** The MDS employs a robust data protection approach designed to facilitate all participants through comprehensive data description (metadata). The data exchange mechanism among partners is enabled through a direct transfer mechanism utilising the Encrypted Data Connector (EDC). This ensures that data sovereignty remains entirely with the involved partners, eliminating the involvement of intermediate third parties, including MDS, in storing or analysing the data, resulting in decentralised data storage at the partner's end. Furthermore, the MDS introduces Connector-as-a-Service (CaaS), a browser-based service provided by MDS partners. This service allows participants to access connectors on demand, enhancing flexibility and ease of use. The EDC connectors, integral to the data exchange process, utilise advanced encryption methods to secure data during transfer, ensuring confidentiality and integrity. Looking ahead, the MDS aims to achieve full integration with the Mobilithek by the end of 2024. The Mobilithek serves as a platform for the exchange of digital information,

Funded by the European Union

predominantly sourced from the public sector, further expanding the capabilities and interconnectedness of the MDS ecosystem.

- **Data Marketplace:** The MDS establishes a dynamic marketplace, offering equal opportunities to the mobility sector for efficient data exchange among its stakeholders and relevant organisations. Within this framework, the MDS ensures the autonomy of data providers, allowing them to always retain ownership of their data. Providers have the discretion to autonomously decide whether and with which participant to engage in data exchange. This approach not only fosters a cross-company data economy but also cultivates innovative, environmentally friendly, and user-centric mobility concepts. Functioning as a marketplace, the MDS serves as a nexus for companies, organisations, and institutions—bridging those seeking to monetise their data assets with those requiring data for pioneering mobility solutions. The MDS facilitates a win-win scenario through targeted data exchange, enhancing collaboration for mutual benefit. As a marketplace, the MDS structures the framework for trustworthy cooperation, ensuring transparency, security, and fairness in the exchange of valuable mobility data. This includes robust mechanisms for data pricing, access controls, and quality assurance, fostering an environment conducive to the growth and advancement of the mobility data ecosystem.

The MDS, in collaboration with different partners, has defined several data use cases in the mobility sector, as discussed in the following.

1. **Identification of Hazard Situations:** The identification of hazard situations for vehicles is crucial for ensuring road safety and preventing potential accidents. Recognizing and understanding hazardous conditions allows for timely intervention and implementation of preventive measures, contributing to overall road safety. Consequently, this collaborative use case with BMW enables vehicles to autonomously identify hazardous conditions, such as heavy rain or black ice, utilising a multitude of sensors. The gathered information is then transmitted to the BMW backend. The effectiveness of assessing potentially dangerous situations increases with the growing number of vehicles reporting, making a substantial contribution to road safety. Furthermore, the data provided through the MDS enhances data coverage, enabling more precise warnings to end-users and consequently elevating overall road safety.
2. **Data Driven-based Optimised Mobility Services:** The data-driven optimisation services use case revolves around the highQ MobilitySuite application, aiming to encourage sustainable, cross-provider, and multimodal transportation solutions for both personal and goods mobility. Using an integrated incentive system, the application incentivises users to adopt sustainable mobility practices by incorporating weather data sourced from the MDS. This weather data is seamlessly integrated with information on mobility services and infrastructures, providing users with a comprehensive overview of the most favourable mobility options in each scenario. Furthermore, users stand to benefit from various rewards when they opt for sustainable transportation choices.

Funded by the European Union

3. **Real-Time Monitoring of Parking:** The real-time monitoring of parking enhances user experience by guiding users to suitable parking spaces, thereby reducing congestion, saving time, and optimising costs. Through collaboration with Mercedes-Benz, the Parking Monitoring interface shares anonymized parking data, including GPS position, park-time, park-out, and vehicle size, with MDS members. The voluntarily provided, anonymized parking data from connected vehicles can be utilised, for instance, to notify end customers of available parking spaces. Additionally, this parking data holds potential applications for municipalities and cities in planning parking spaces. The secure data transfer facilitated by the MDS contributes to increased user-friendliness in mobility. The extended version of the parking monitoring application caters to municipalities aiming to minimise parking search traffic and enhance the balanced utilisation of existing parking spaces. Developed in collaboration with the MDS, the OptiPark solution by Urban Mobility Innovations offers real-time and forecast data on parking area occupancy. Sensor data from vehicles, in conjunction with existing parking sensors like barriers or cameras, is integrated into the OptiPark solution. This combined approach enhances the accuracy of real-time monitoring and provides more precise forecast data for optimal parking space management.

Nevertheless, crucial concerns regarding data interoperability, security of energy supply, cybersecurity, privacy, and consumer protection require oversight from regulatory frameworks. These issues underscore the need for active guidance and intervention to ensure their effective management and proper implementation within the evolving energy landscape.

2. Requirement Analysis of Data Governance for Energy Data Space

The escalating concerns surrounding data security, privacy, and quality in the ever-evolving technological advancements in renewable energy sources, coupled with the emergence of stakeholders in energy, smart city, mobility, and climate sectors, underscore the imperative to harness the capabilities of a robust and sustainable data governance (DG) framework [31]. Such frameworks serve as pivotal drivers behind the proliferation of data regulations, exemplified by initiatives like the GDPR. This section conducts a detailed requirement analysis of distributed data governance, delving into its significance, benefits, types, key architectures, best practices for implementation, alignment with regulatory standards, and performance monitoring. It provides a comprehensive understanding of the multifaceted aspects surrounding effective data governance in the energy landscape.

2.1. Importance of Data Governance in Energy Data Space

A data governance framework encompasses a defined set of rules, processes, and responsibilities that govern the collection, organisation, storage, and utilisation of energy data within a data space [32]. The primary objective of such a framework is to establish a standardised approach to energy data management, ensuring its integrity, facilitating internal team utilisation, and securing

Funded by the European Union

against security risks. In the absence of a robust data governance framework, individual stakeholders may adhere to disparate standards and processes, leading to the formation of data silos that can result in inefficiencies. This fragmentation hinders the assurance of data quality and compliance with privacy regulations. Following are the key factors collectively driving the successful implementation and sustained effectiveness of a data governance framework, ensuring that the energy data is managed with integrity, security, and compliance [33].

- **Prioritisation Services:** In an energy data space, the maintenance of data quality, security, and compliance emerges as essential services that demand vigilant attention due to the emerging stakeholders in the energy landscape. Therefore, the data governance framework prioritises data quality, security, and compliance within the data space to ensure seamless operations among participating stakeholders. Data quality ensures that information is accurate, reliable, and suited for its intended purpose. Security measures act as a safeguard against unauthorised access, fortifying sensitive data of consumers and prosumers against potential breaches or leaks. Compliance entails strict adherence to legal and regulatory requirements, such as privacy laws, ensuring the stakeholders operate within the defined boundaries of established standards. This prioritisation establishes a foundational framework for trustworthy, secure, and legally compliant data management in the energy sector.
- **Roles and Policies in Effective Data Management:** A clear definition of roles, responsibilities, policies, and standards is a cornerstone of effective data management within a data governance framework for the energy sector. Roles and responsibilities delineate accountability among various stakeholders for different aspects of data handling, specifying who is using the data and for what purpose, thereby preventing confusion and ensuring accountability. Well-defined policies guide decision-making processes, while standards set benchmarks for data quality, structure, and usage. This clarity facilitates streamlined operations, reduces ambiguity, and contributes to a more efficient and structured environment for energy data.
- **Collaborative Data Governance:** Enhanced collaboration among stakeholders from various levels such as TSO, DSO, utility companies, energy aggregators, prosumers, consumers, and E-mobility operators is instrumental in achieving data governance goals. Collaboration breaks down departmental silos, fostering a unified approach to data management within the energy data space. It ensures that data-related decisions consider the perspectives and needs of all relevant stakeholders. This collaborative effort enhances the consistency and effectiveness of data governance practices, promoting a holistic and integrated approach to data handling and usage. The synergy derived from cross-platform and emerging stakeholder collaboration contributes to the overall success of data governance initiatives.

2.2. Types of Data Governance Approaches

When designing a data governance framework for energy data space, it is crucial to outline operational guidelines, establish robust oversight mechanisms, and build a resilient infrastructure for data ownership and decision-making. This section discusses three fundamental data

Funded by the European Union

governance models: the centralised model, the decentralised model, and the hybrid model and their characteristics facilitating the energy data space [34].

2.2.1. Centralised Data Governance

In a centralised data governance model within the energy data space, the establishment of a singular, designated authority such as the utility company is crucial for the management of the production, energy consumption and distribution data assets [35]. This authoritative figure, commonly known as the data governance lead, functions at the core of the system, undertaking pivotal roles in decision-making, strategic planning, and policy implementation within the data governance program. The key elements of centralised data governance include:

- **Decision-Making Authority:** The data governance lead possesses decision-making authority concerning data-related policies, standards, and procedures for the utilisation among the stakeholders. This involves setting guidelines for data quality, security measures, and overall data management strategies.
- **Policy Implementation:** The lead is responsible for translating data governance policies into actionable measures, ensuring compliance across stakeholders. This includes implementing data access controls for those utilising the data, adhering to data owner regulations, data classification schemes, and other technical security measures.
- **Master Data Management:** In some cases, the centralised model incorporates the data governance lead into the Master Data Management process. This involves overseeing the creation and maintenance of master data in the centralised data space while being responsible for the data distribution among the representative stakeholders, ensuring its accuracy and consistency across the participating stakeholders.
- **Data Distribution Framework:** The centralised model may also entail a centralised data distribution framework, where the lead oversees the dissemination of energy generation data of the prosumers to the energy market with the end-users based on predefined criteria. This could involve the establishment of data catalogues, data dictionaries, and data access protocols.
- **Data Quality Monitoring:** Centralised data governance typically involves the implementation of robust data quality monitoring mechanisms within the data space. The lead oversees the establishment of data quality metrics, continuous monitoring processes, and remediation strategies to address data quality issues promptly for smooth operation and management of the energy data and its distribution among the participating stakeholders. Centralised governance allows for a coordinated and standardised approach to maintaining data quality throughout the data space.
- **Data Stewardship:** The lead data governance may appoint data stewards responsible for specific data domains such as for the energy consumption data or the prosumers surplus data. These stewards work closely with technical teams and the lead to enforce data governance policies, resolve data-related issues, and ensure adherence to data standards.

Funded by the European Union

- **Metadata Management:** Metadata Management in the energy sector is crucial for providing a comprehensive understanding of data assets. This encompasses the centralised management of metadata, including data definitions, lineage, and relationships, specifically tailored to the needs of various stakeholders. In the energy sector, where diverse stakeholders such as TSOs, DSOs, utility companies, energy aggregators, prosumers, consumers, and E-mobility operators are involved, effective metadata management becomes essential. Utilising metadata repositories and tools becomes paramount to ensure streamlined operations, foster collaboration, and enhance overall data governance in the dynamic energy landscape.

Advantages: The centralised data governance has several advantages and associated challenges as discussed in the following.

- **Efficiency Enhancement:** Centralised data governance facilitates optimal task prioritisation, allowing teams to concentrate on core activities rather than expanding efforts on the collection, management, and dissemination of data.
- **Quality Assurance:** Consistency in data across the entire data space empowers stakeholders to make more informed decisions, ensuring a higher standard of data quality and accuracy.
- **Enhanced Security Measures:** Streamlined data tracking and security protocols within a centralised model mitigate the risks associated with mishandling or unauthorised access to sensitive consumers and prosumers data, bolstering overall data security.
- **Cost Optimization:** Centralisation of data operations leads to resource efficiency, reducing the need for redundant processes and optimising resource allocation, ultimately contributing to cost control.

Challenges:

- **Bureaucratic Challenges:** The top-down nature of centralised models may introduce bureaucratic hurdles, potentially impeding operational agility and responsiveness to specific stakeholder requirements across different areas.
- **Insufficient Flexibility:** Centralised governance, if overly rigid, might struggle to accommodate the diverse and evolving needs of distinct emerging stakeholders such as electric battery swapping operators and thus, posing a risk of reduced adaptability to changing circumstances.
- **Potential Resistance:** The imposition of centralised controls may face resistance from decentralised units, affecting the overall acceptance and effectiveness of the governance model.
- **Inadequate Customisation:** A one-size-fits-all approach may not adequately address the requirements of each stakeholder’s area and their emerging service requirements, potentially limiting the effectiveness of the centralised model in meeting specific needs.

Funded by the European Union

2.2.2. Decentralised Data Governance

In a decentralised data governance model for energy systems, an oversight committee typically assumes responsibility for designing and managing the data governance strategy within the energy data space [36]. The nominated committee serves as the central governing body, overseeing the alignment of strategies with data space objectives and compliance with energy standards. Concurrently, individual functional stakeholders within the data space assume responsibility for creating and managing their own data sets. These stakeholders also handle the complex task of distributing information to end-users within their designated data spaces. This decentralised framework empowers the participating stakeholders to exercise autonomy in tailoring data management practices according to the requirements of their data spaces. The oversight committee plays a pivotal role in orchestrating these decentralised efforts, ensuring coherence in overarching data governance objectives and strategies. Within the data space, this distributed structure enhances agility and responsiveness, allowing each functional stakeholder to optimise data management processes based on technical and operational considerations within the data spaces. The following are the key characteristics of decentralised data governance.

- **Data Ownership and Stewardship:** Each functional stakeholder becomes a data owner and steward, responsible for the data within its purview. This involves implementing technical measures for data profiling, metadata management, and ensuring data quality.
- **Data Distribution Protocols:** Decentralised governance requires robust protocols for data distribution. This involves the implementation of secure data sharing mechanisms, version control, and access management to ensure that data is appropriately disseminated among relevant energy users.
- **Interoperability Standards:** To ensure seamless collaboration and integration across decentralised stakeholders, adherence to interoperability standards is crucial. This involves implementing standardised data formats, Application Programming Interfaces (APIs), and communication protocols to facilitate data exchange between different functional stakeholders.
- **Data Security and Privacy Controls:** Implementing decentralised governance requires robust data security measures, including encryption, access controls, and data masking techniques to protect sensitive information. Privacy-enhancing technologies, such as differential privacy, may also be considered.
- **Blockchain and Distributed Ledger Technologies:** Leveraging blockchain or distributed ledger technologies can offer a decentralised and immutable record of both energy data and financial transactions in peer-to-peer trading. This enhances data traceability, transparency, and tamper-proofing, ensuring the integrity of data across multiple communicating stakeholders.
- **Smart Contracts for Governance Rules:** Smart contracts, programmed self-executing contracts with the terms of the agreement directly written into code, can be employed

Funded by the European Union

for automating data governance rules. This ensures that agreed-upon data governance policies are consistently enforced across decentralised communicating stakeholders.

- **Decentralised Identity Management:** Implementing decentralised identity management solutions, such as self-sovereign identity, allows for secure and privacy-enhanced user authentication and authorisation across decentralised data units.
- **Decentralised Data Analytics and Processing:** Each functional unit may have its analytics and processing capabilities. Ensuring compatibility and standardisation in tools and technologies is essential for achieving a cohesive data analytics strategy across the decentralised energy landscape.
- **Data Versioning and Change Tracking:** Maintaining a decentralised approach requires robust mechanisms for versioning and tracking changes to all the energy data shared across the participating stakeholders. Implementing technologies like Git for data version control can be valuable in this context.
- **Decentralised Auditing and Compliance:** Implementing decentralised auditing mechanisms ensures that each stakeholder adheres to regulatory compliance and internal governance policies. This involves the use of audit logs, checksums, and cryptographic hashing for data integrity verification.

Advantages and Challenges: The shift towards decentralised data governance represents a substantial change in the management of data spaces, recognising the varied operations within the data environment for the energy landscape. However, this transformative approach is not without its challenges. Following are both the advantages and challenges inherent in decentralised data governance.

- **Enhanced Representation:** Decentralised data governance excels in addressing the diverse needs and distinct challenges across various emerging stakeholders, meeting their evolving requirements. It offers a comprehensive approach that caters to the intricacies of each sector.
- **Improved Data Quality:** The data generated within a decentralised model is inherently more relevant and reliable as it originates from the end-users who directly engage with it in their operational roles. This user-driven data creation process ensures a higher degree of accuracy, applicability, and data management autonomy.
- **Optimised Operational Efficiencies:** The implementation of decentralised data governance is characterised by a streamlined setup process, fostering a more agile and adaptable framework that effortlessly accommodates the evolving needs and dynamic requirements of stakeholders. This adaptability contributes to increased operational efficiencies.
- **Collaborative Maintenance:** In a decentralised model, the responsibility for executing and maintaining the data governance strategy is collectively shared among multiple data owners/stakeholders. This collaborative approach ensures that the governance strategy remains responsive to evolving challenges and is consistently aligned with the dynamic nature of the energy landscape.

Funded by the European Union

Challenges:

- **Inconsistent Master Data:** One of the risks associated with decentralised models is the potential for inconsistencies and duplications in master data, as each of the data owners is responsible managing their own data. This can impact consensus-building, reporting accuracy, and decision-making processes. Implementing advanced data reconciliation techniques, automated validation checks, and periodic audits can mitigate these risks, ensuring a harmonised and accurate master data landscape.

2.2.3. Hybrid Data Governance

The hybrid data governance model strikes a balance between maintaining consistency and standardisation across the energy data space while allowing for flexibility and autonomy at the stakeholder unit level [37]. This approach optimises the benefits of centralised control and local customisation, fostering a collaborative and agile data governance environment with the following key characteristics.

- **Centralised Framework and Technology:**
    - *Metadata Repository:* Establish a centralised metadata repository to cater to the diverse stakeholders involved in energy generation, consumption, billing, metering, surplus energy, and market participation. This repository is designed to function as a comprehensive catalogue covering all data assets across the entire data space. It encompasses vital information related to data definitions, lineage, quality, and usage.
    - *Master Data Management:* Establish a master data management system that involves designing a comprehensive data model that encompasses critical entities like consumers, prosumers, energy sources, billing details, and metering data. The metadata repository is linked with the master data management system that documents data definitions, lineage, quality metrics, and usage.
    - *Data Catalogue and Discovery Tools:* Integrate data catalogue tools that facilitate the discovery, profiling, and classification of various data assets within the energy ecosystem, covering aspects such as energy generation, consumption patterns, billing information, metering data, and market participation. The integration of these data catalogue and discovery tools ensures a technically sound and centralised approach to managing and utilising data assets within the energy domain.
- **Governance Best Practices:**
    - *Data Stewardship Framework:* Define a robust data stewardship framework for ensuring consistent data quality, security, and compliance practices that involves the definition of standardised roles and responsibilities for data stewards, delineating their engagement with critical data entities such as consumers, prosumers, energy details, billing information, and metering data. The framework integrates data quality metrics, security protocols, and compliance

Funded by the European Union

measures to quantitatively measure data quality, enforce access controls, and verify adherence to regulatory standards. Continuous improvement is embedded through feedback mechanisms, fostering a dynamic and technically proficient approach to data stewardship across the entire energy organisation.

 - *Policy Management:* By establishing a centralised repository for these policies, version control mechanisms, and automated enforcement processes, the energy system ensures a unified and up-to-date framework. Real-time monitoring and automated alerts help maintain adherence to established policies, while comprehensive auditing capabilities provide transparency and accountability.

- **Autonomous Operation by Application Owners:**
  - *Local Governance Committees:* For effective governance of energy data, it is essential to institute Local Governance Committees within each distinct business area within the energy system. These committees are composed of representatives from various domains, including data stewardship, IT, and energy policy makers, TSO, DSO, and market operators. The primary responsibility of these committees is to customise and tailor overarching data governance principles to address the unique requirements and intricacies of the specific energy domain such as TSO, DSO, and utility companies.
  - *Customization of Standards and Procedures:* The hybrid approach grants application owners the flexibility to customise data standards, policies, and procedures to align closely with the unique requirements of the energy market. Allowing for this level of customisation, the energy system promotes adaptability and responsiveness to the diverse needs and challenges presented by various entities, such as TSO, DSO, utility companies, energy aggregators, charging station operators, and other stakeholders. This approach fosters a more effective data governance framework, where standards and procedures are optimised to enhance the performance and efficiency of specific applications and processes within the broader energy ecosystem.
- **Interoperability and Communication:**
  - *Interconnected Systems:* The approach focuses on the implementation of interconnected systems that establish seamless communication channels and interoperability between the centralised data governance structure and autonomous application owners. This involves creating robust mechanisms for collaboration, such as regular reporting, feedback loops, and timely updates on changes to governance policies. By fostering effective communication, these interconnected systems ensure a cohesive relationship between the central governance structure and application owner's stakeholders within the energy sector. This approach enables the sharing of critical information, insights, and policy updates, promoting a synchronised and cooperative data governance environment.

Funded by the European Union

    - *Metadata Exchange:* The hybrid approach enables seamless metadata exchange between the centralised repository and localised systems. This entails establishing mechanisms that facilitate the smooth flow of metadata, ensuring that the overall metadata catalogue remains comprehensive and up to date, while still allowing individual stakeholders to maintain autonomy of their data. This approach ensures that changes, updates, and additions to metadata are propagated seamlessly throughout the entire energy system, promoting consistency and accuracy in metadata management while respecting the autonomy of specific stakeholders.

- **Audit and Monitoring:**
    - *Centralised Monitoring Tools:* The hybrid approach employs centralised monitoring tools to enhance oversight and ensure adherence to governance policies, data quality, and compliance standards across the data space. These tools offer a unified platform for monitoring various aspects of data governance within the energy sector and provide visibility into the implementation of governance policies, track data quality, and assess compliance levels, enabling a holistic understanding of the data landscape. This approach facilitates proactive identification of potential issues, deviations from standards, and areas for improvement, ultimately contributing to the overall effectiveness and reliability of the energy system's data governance framework.
    - *Local Monitoring:* The hybrid approach empowers application owners with the necessary tools to monitor and audit data within their respective purview. This empowerment enables localised oversight and fosters continuous improvement within the energy domain. This localised approach promotes accountability, transparency, and agility, allowing for swift identification and resolution of issues, as well as ongoing data space of data processes and systems. Ultimately, empowering application owners with local monitoring tools enhances the overall effectiveness and efficiency of the energy system's data governance framework.

The hybrid data governance framework, leveraging a combination of centralised and decentralised approaches, offers several advantages and challenges to the energy landscape, as discussed in the following.

Advantages:

- **Enhanced Autonomy:** The framework empowers the participating stakeholders to independently manage and scale their data operations without causing disruptions to other stakeholder's data and their operations.
- **Efficient Issue Resolution:** The framework supports the accelerated resolution of issues by addressing them at the point of occurrence, minimising delays, and bottlenecks.
- **Increased Agility: The hybrid framework** facilitates quick experimentation and adjustments to the stakeholder data in response to evolving energy market and consumption needs, fostering a more agile and responsive environment.

Funded by the European Union

Challenges:

- **Expertise Requirement:** The framework demands in-depth expertise within each respective area of the stakeholders for effective autonomy and management, thus necessitating a robust understanding of diverse energy sector domains ranging from generation to aggregators, and to the consumers with localised prosumers.
- **Consistency Challenges:** The framework requires continuous monitoring and additional measures to ensure data consistency and coordination among stakeholders across the energy landscape, mitigating the risk of discrepancies and maintaining unified data standards.

2.3. Comparative Study of the Different Types of Data Governance Framework

Adhering to the ISO/IEC 38505 guideline for data governance, we conducted an evaluation of centralised, decentralised, and hybrid data governance models, as shown in Table 1 [38]. We assessed parameters such as data quality, security, governance adoption, metadata management, stewardship, ownership, governance processes, data usage, and tools. Compliance levels were categorised as high, medium, or low, indicating alignment with the standard. The medium-to-high range represents variations in compliance depending on the specific governance framework.

Table 1. Comparative analysis of the centralised, decentralised, and hybrid data governance according to the ISO/IEC 38505 standard

Performance	Centralised	Decentralised	Hybrid
Data Quality	High	Medium	Medium-to-High
Data Security	High	Medium	Medium-to-High
Governance Adoption	Medium-to-High	High	Medium-to-High
Metadata Management	High	Medium	Medium-to-High
Data Stewardship	Medium-to-High	Medium	Medium-to-High
Data Ownership	Medium	High	Medium-to-High
Governance Process	High	Medium	Medium-to-High
Data Usage	Medium-to-High	Medium	Medium-to-High
Data Governance Tools	High	Medium-to-High	Medium-to-High
Alignment with ISO/IEC 38505 standard	Medium-to-High	Medium	Medium-to-High

Depending on the data governance requirements, any of these approaches (Table 1) can be applied. In the case of a hybrid approach, it can lead to higher autonomy for data providers while supporting centralization to allow centralized entities to manage metadata, which connects data providers and users.

Funded by the European Union

2.4. Design Principle for the Data Governance Framework in the Energy Data Space

2.4.1. Conceptual Framework of Data Governance

The foundational design of the data governance framework for the energy data space is rooted in addressing three crucial questions from distinct perspectives, as presented in the following [39].

- It delineates the decisions that necessitate a robust framework, delving into the specifics of critical decision points within the energy sector.
- It defines the nature of the data involved, incorporating technical intricacies related to energy data, encompassing aspects such as generation, consumption, distribution, and market participation.
- The framework intricately identifies and assigns roles that should actively participate in the decision-making process, incorporating technical expertise across various domains within the energy landscape.

This approach establishes a strong and technically sound relationship among data, role, and decisions, in the data governance framework for the energy data space, ensuring comprehensive and effective implementation, as presented in Figure 3 (a). The figure underscores that the concept of data governance is composed of three fundamental elements: data, roles, and decision-making pertaining to the data, as discussed in the following.

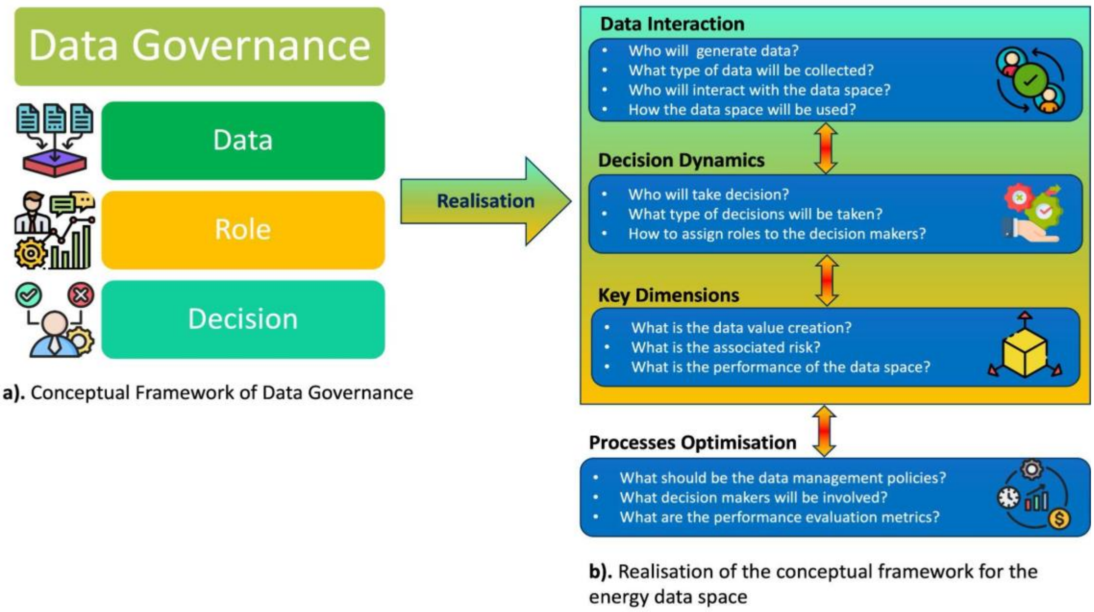

Figure 3. The design principles of developing a data governance framework for the energy data space. (a) A conceptual framework for developing data governance, (b) A realisation of the data governance framework for managing the energy data space.

Funded by the European Union

- **Data:** Data entails the comprehensive handling, administration, and utilisation of energy-related data, encompassing intricate details such as stakeholder data, market specifics, power generation metrics, and consumer consumption patterns across the entirety of the energy data landscape.
- **Role:** The concept of role pertains to the various entities or stakeholders involved in decision-making and implementation processes. These stakeholders play crucial roles in shaping and executing decisions related to energy data. The significance of roles in data governance can be viewed as a facilitator that enables the effective execution of data governance practices. These roles may encompass entities such as energy providers, regulatory bodies, consumers, and technology experts, each contributing unique perspectives and responsibilities. These roles serve as key enablers, guiding and influencing the implementation of data governance practices in the energy data space.
- **Decision:** The decision-making process in data governance involves the control and governance of data within the energy data space. It encompasses the establishment of access controls tailored to specific stakeholders and adherence to policies crafted by the designated roles. These decisions wield a comprehensive influence over the entire lifecycle of data, from its collection and management to its utilisation. Decision-making by roles involves implementing fine-grained access controls to ensure authorised stakeholders have specific levels of access to various subsets of energy-related data, extending beyond mere permissions to also dictate data utilisation in accordance with predefined policies.

2.4.2. Realisation of the Data Governance Framework

The conceptual framework, depicted in Figure 3(a), serves as the basis for constructing a specialised data governance framework designed specifically for the energy data space, as illustrated in Figure 3(b) [40]. This framework includes a set of meticulously organised questions, categorised into four distinct service domains, as detailed in the following discussion.

2.4.2.1. Data Interaction

When formulating a data governance framework for the energy data space, it is imperative to address several critical questions that primarily centre around data generation entities, data types, and data utilisation entities, as shown in Figure 4. In the energy data space, data generation is often initiated by diverse sources, including:

- **Data Generation Sources:** Data generation sources encompass a variety of entities within the energy ecosystem. These include power generation facilities, smart grid technologies, renewable energy sources (such as solar and wind), utility companies, energy aggregators, parking lot operators, E-Mobility Service Providers, Charging Station Operators, Electric Vehicles, Household Metering Data, and Prosumers.
- **Types of data collection:** The energy data space encompasses a diverse array of data, including generation data (such as generation outputs, grid performance, and equipment status), market data (covering pricing information, demand forecasts, and market trends), environmental data (comprising emissions, weather conditions, and

Funded by the European Union

sustainability metrics), consumer data (including consumption patterns, preferences, and billing information), and mobility data (encompassing charging session data, mobility patterns, and vehicle telemetry). Additionally, various entities within the energy ecosystem contribute other diverse datasets, depending on their specific roles and functions.

- **Interacting Entities:** Several entities will interact with the energy data space, including energy regulators, consumers, energy aggregators, E-mobility service providers, and other stakeholders based on their respective roles.
- **Data Space Utilisation:** The energy data space is designed for multifaceted applications, incorporating advanced techniques for market analysis, operational optimisation, environmental impact assessment, consumer engagement, and mobility optimisation. In energy data space, market analysis involves leveraging datasets for assessments of market trends, demand forecasting, and pricing strategies. Operational optimisation utilises real-time data to enhance efficiency in power generation, distribution, and consumption. Environmental impact assessment employs data analytics to gauge and minimise carbon footprint, ensuring sustainable energy practices. Consumer engagement utilises consumption patterns, preferences, and billing information to provide users with personalised insights for informed decision-making. Mobility optimization focuses on managing fleets, optimising charging infrastructure, and enhancing electric vehicle performance based on data-driven insights.

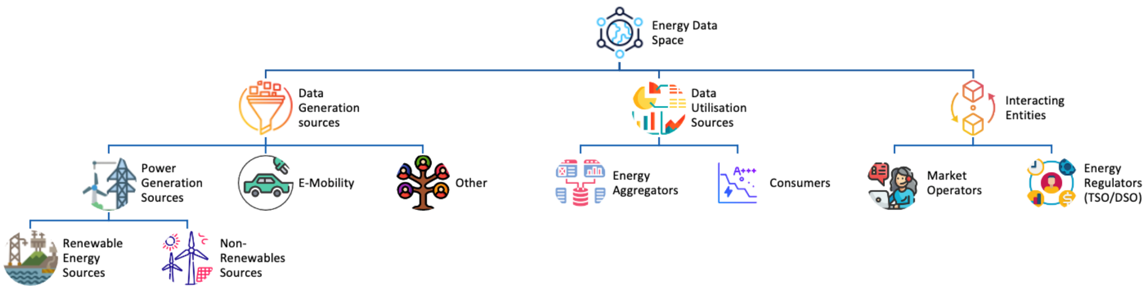

Figure 4. An illustration of the energy data space highlighting the data generation, utilisation and interacting sources to the data space.

2.4.2.2. Decision Dynamics

In the data space, decision dynamics play a crucial role in identifying and selecting the suitable entities that are responsible for managing data. In decentralised data governance for the energy data space, decision-making involves a collaborative effort among various stakeholders. The key decision-makers include:

- **Energy Regulators:** Energy regulators play a pivotal role in the energy data space, wielding authority in decision-making concerning regulatory policies, compliance standards, and market oversight. Their responsibilities encompass setting regulations for data sharing to facilitate transparent information exchange within the industry. Additionally, energy regulators focus on ensuring fair market practices, creating a level playing field for stakeholders. Furthermore, their role extends to establishing stringent

Funded by the European Union

standards for data security, aiming to safeguard the integrity and confidentiality of critical energy-related information.

- **Utility Companies:** Utility companies play a crucial role in decision-making concerning energy distribution, infrastructure investments, and operational optimisation. Their responsibilities include determining optimal distribution strategies, making strategic investments in grid enhancements, and utilising data for efficiency improvements. Importantly, their decisions extend to operational optimisation by leveraging insights to enhance efficiency in power generation, distribution, and consumption.
- **Data Governance Bodies:** These are designated stakeholders responsible for decision-making regarding data governance policies, access controls, and ensuring data quality within the energy data space. Their pivotal role involves defining comprehensive data governance frameworks, including access permissions and policies for data utilisation.
- **Consumers:** The energy consumers play a vital role in the energy data space, utilising data to make informed decisions about energy consumption patterns, preferences, and participation in demand-response programs. Their main role in decision-making involves adjusting consumption based on data insights, selecting energy plans that align with their preferences and needs, and actively engaging in energy-saving practices.
- **E-Mobility Service Providers:** E-mobility service providers are at the forefront of optimising charging infrastructure, managing fleets, and enhancing EV performance. Their primary decisions involve planning charging station locations strategically, optimising fleet routes based on data-driven insights, and continually improving EV charging efficiency.

These entities are tasked with executing various types of decisions, as elaborated in the following discussions.

- **Operational Decisions:** Operational decisions centre around various operations, aiming to optimise energy distribution, manage grid loads, and enhance the efficiency of power generation facilities.
- **Strategic Decisions:** Strategic decisions focus on formulating long-term plans for infrastructure development, adopting new technologies, and implementing sustainability initiatives in the energy landscape.
- **Data Governance Decisions:** Data governance decisions involve defining access controls, establishing data quality standards, and ensuring compliance with data protection regulations for energy data.
- **Consumer-Driven Decisions:** Consumer-driven decisions include tailoring energy plans based on consumer preferences, implementing demand-response initiatives, and enhancing consumer engagement strategies to optimise energy consumption and costs.
- **Mobility Optimisation Decisions:** The emergence of mobility in the energy system requires decisions on mobility optimisation, including planning optimal locations for charging stations, managing electric vehicle fleets, and leveraging data for predictive maintenance.

Funded by the European Union

Depending on the type of data governance framework, such as in the centralised approach, a governing body is responsible for most decisions. In the decentralised approach, participating stakeholders take charge of decisions related to their data. In the case of a hybrid framework, stakeholders are responsible for decisions regarding their data, while a governing body monitors the performance and overall utilisation of the data space. In any scenario, assigning roles to decision-makers in the energy data space requires a thoughtful and strategic approach.

- **Identify Expertise:** Assess the expertise and domain knowledge of potential decision-makers in areas such as regulation, technology, and data governance.
- **Define Responsibilities:** Clearly define the responsibilities of each decision-maker based on their expertise and the specific needs of the energy data space.
- **Collaborative Approach:** Foster collaboration among decision-makers to ensure a holistic and well-informed decision-making process that considers various perspectives.
- **Regular Training and Updates:** Provide regular training and updates to decision-makers to keep them informed about the evolving landscape of energy data and emerging technologies.
- **Data-Driven Decision-Making:** Encourage decision-makers to adopt a data-driven approach, leveraging insights from the energy data space to inform their decisions.
- **Adaptability:** Recognise the dynamic nature of the energy sector and ensure decision-makers are adaptable to changes, emerging technologies, and evolving regulatory landscapes.

2.4.2.3. Key Dimensions

While designing data governance for the energy data space, a comprehensive consideration of data value creation, associated risks, and the ongoing performance of the data space is crucial. By addressing these key dimensions thoughtfully, the energy data governance framework can ensure not only the security of data but also maximise its utility for strategic decision-making and innovation within the dynamic energy sector.

- **Data Value Creation:** Data value creation supports the optimisation of existing operations over the data. Therefore, understanding, and maximising data value creation hold significant importance while developing the data governance framework for the energy data space. This involves identifying the types of insights and innovations that can be derived from the data. For example, data analytics applied to energy consumption patterns can lead to more efficient resource allocation and informed decision-making. By defining clear data ownership, access, and utilisation policies, data governance framework can ensure that data is leveraged to its full potential, creating value through improved operational efficiency, strategic planning, and enhanced customer services.
- **Associated Risk:** Assessing and managing risks is a critical dimension in data governance for the energy data space. Risks may arise from data breaches, unauthorised access, or inaccuracies in data interpretation. A robust governance framework must incorporate measures to safeguard sensitive information, ensure compliance with data protection regulations, and establish protocols for data quality assurance. Implementing encryption,

Funded by the European Union

access controls, and regular audits can mitigate risks, fostering a secure environment for data management.

- **Performance of the Data Space:** Evaluating the performance of the data space is essential for ensuring its effectiveness in meeting organisational objectives. This dimension involves monitoring key metrics such as data availability, accuracy, and accessibility. Additionally, assessing the responsiveness of the data space to evolving needs and technologies is crucial. Performance metrics can include data processing speed, system reliability, and the adaptability of the governance framework to changes in the energy landscape. Regular performance assessments enable organisations to identify areas for improvement and optimise the overall functionality of the energy data space.

2.4.2.4. Process Optimisation

Process optimisation in data governance for the energy data space involves streamlining workflows, enhancing data quality, and improving the efficiency of data-driven operations.

- **Workflow Streamlining:** Workflow streamlining in the context of data governance for the energy data space focuses on optimising several services, including the enhancement of data acquisition, processing, and dissemination workflows to facilitate faster and more accurate decision-making.
- **Data Quality Enhancement:** The service of data quality enhancement can be achieved by implementing measures to ensure data accuracy, completeness, and consistency. This involves minimising errors and enhancing the reliability of information.
- **Operational Efficiency:** The integration of automated tools and technologies for data processing aims to reduce manual efforts and improve the overall operational efficiency of the data governance framework.
- **Adaptability to Change:** Robustness is a key feature of the data governance framework. Therefore, designing a flexible governance framework that can adapt to changes in the energy landscape, technologies, and regulatory requirements is essential.
- **Continuous Improvement:** Adaptive improvement through stakeholder feedback and evolving technological enhancements is a key aspect of the data governance framework. Therefore, establishing a feedback loop for continuous improvement, incorporating insights from performance evaluations and stakeholder feedback to refine data governance policies and processes, is essential.

2.5. ISO/IEC 38505-1 based Data Governance Framework for Energy Data Space

ISO/IEC 38505-1 offers technical guidelines for data governance and management within the data space through a data map. This section presents a detailed development of data governance for the energy data space following the ISO/IEC 38505-1 map [41].

Funded by the European Union

2.5.1. ISO/IEC 38505-1 Accountability Map for Data Governance in Energy Data Space

ISO/IEC 38505-1 provides a data accountability map that serves as a framework for managing the data space, as illustrated in Figure 5. This map attributes value, risk, and constraints to data elements such as collection, storage, reporting, distribution, and disposal. It facilitates the identification of concerns that necessitate the definition and implementation of data governance policies within the data space. The advancement in technology within renewable energy sources and the increasing involvement of stakeholders in the energy system have led to the generation of a substantial amount of data. This data is expected to be managed in the energy data space, where advanced technologies facilitate the processing of large data volumes from diverse sources, making the extraction of value economically viable for the growing number of emerging stakeholders. The governing body plays a crucial role in shaping the overall data strategy for the data space, delineating how the space intends to leverage data to extract value for its stakeholders. Aligned with this strategy, the governing body establishes the data risk appetite, defining the level of risk related to data that the data space is willing to pursue or retain. The governing body must consider regulatory constraints, legislative requirements, societal needs, cultural norms, and existing stakeholder policies, which may limit the collection and utilisation of data. A detailed accountability map, based on the principles of value, risk, and constraints, is presented for the implementation of data governance policies within the data space, following the guidelines of ISO/IEC 38505-1.

Figure 5. An illustration of ISO/IEC 38505-1 standard based data governance map [41].

This map provides a structured approach to ensuring effective and responsible data governance practices while considering the unique challenges and opportunities present in the dynamic energy sector. In Table 2 below, we elucidate the ISO/IEC 38505-1 accountability concept for data governance in the energy data space.

Table 2. Data governance for energy data space according to the ISO/IEC 38505-1 accountability map [41].

Data Map Element	Value	Risk	Constraints
Collect	Establish the level at which stakeholders will utilise data. **Example:** The smart grid oversight body decides whether to utilise utility data for operational efficiency or monetization to align with strategic objectives.	Acknowledge the risks linked to data collection and utilisation, agreeing upon an acceptable level. **Example:** Privacy breach in detailed energy data: collection risks exposing individual consumption patterns.	Approve data policies, considering quality, privacy, consent, and transparency in energy governance. **Example:** Ensures energy data policies cover quality, privacy, consent, and transparent use.
Store	Approve energy data storage policies, ensuring resources for value extraction. **Example:** Allocate storage for grid insights; enhance operational efficiency	Ensure that the Information Security Management System covers data/technology suppliers in the energy space, allocating adequate resources, controls, and trust. **Example:** Secure data flow with tech suppliers; mitigate cybersecurity threats.	Align data storage with collection constraints in energy space. **Example:** Storage compliance for real-time grid data; enhance operational insights.
Report	Employ tools for maximising energy data report **Example:** Utilisation of analytics tools (AI/ML) for grid insights; optimise energy operations.	Establish the significance of the context of the energy data from a wider perspective, including cultural norms and its potential misinterpretation in aggregate. **Example:** Cultural factors daily routines and attitudes towards conservation that impact decisions related to energy use	Establish the importance of the relationship between energy data and its constraints, crucial for aggregated datasets. **Example:** Harmonise diverse datasets; ensure accurate grid analytics.
Decide	Ensure energy data culture	Deliver energy data in	Set expectations for

Funded by the European Union

	aligns with strategy, including behaviours (data access practices, data-driven decisions, stakeholders learning from the decision process). **Example:** Data-driven decisions in grid optimisation; enhance energy efficiency.	format for accountable, automated, or human decision-making. **Example:** Data analytic based automated for decision-making; delegate load balancing decisions with data risk considerations.	the decision process for the output of the decision as it has its own value, risk, and constraint as new data. **Example:** Decision on grid optimisation generates new data with efficiency insights; governance sets expectations and assigns responsibilities.
Distribute	Establish an energy data distribution policy that is aligned with the strategic plans of the data space. **Example:** Implement a data-sharing policy for grid analytics to support the energy transition strategy.	Ensure managers implement controls to prevent inappropriate energy data distribution, mitigating risks. **Example:** Implement access controls to secure grid analytics data from unauthorised distribution, ensuring compliance.	Ensure energy data distribution rights are implemented and respected by participating stakeholders for maintaining compliance. **Example:** Enforce distribution agreements to protect grid analytics data; ensure stakeholder adherence to data rights.
Dispose	Approve policies for energy data disposal when no longer valuable or sustainable. **Example:** Implement a policy for data disposal post-utilisation, adhering to sustainability goals and regulatory requirements.	Direct data managers to implement secure and permanent energy data disposal processes, mitigating risks. **Example:** Ensure grid data is securely destroyed to prevent unauthorised access, addressing potential cybersecurity threats.	Monitor energy data retention and disposal obligations, ensuring implemented processes align with policies. **Example:** Regularly audit grid analytics data disposal methods to confirm secure and compliant destruction.

The ISO/IEC 38505-1 accountability map encompasses a comprehensive concept, aiding the implementation of a data governance framework across diverse domains. Governance bodies should

Funded by the European Union

adhere to these guidelines, aligning them with their respective organisations and stakeholders to effectively manage their data.

3. Energy Data Space Framework and Their Data Governance

In the dynamic landscape of the energy and E-mobility sector, the convergence of diverse stakeholders, including power grid entities, mobility operators, traffic management systems, charging station operators, and EV users, has ushered in a new era characterised by unprecedented data proliferation. This surge in data volume necessitates a standardised approach to address the challenges of seamless integration, secure storage, efficient processing, and governance. As these stakeholders interact within the intricate web of energy ecosystems, the importance of a well-defined data space architecture becomes evident. In this section, we embark on a comprehensive exploration of different data space architectures, recognizing their pivotal role in facilitating data governance and interoperability. By delving into detailed analyses from the perspectives of governance and interoperability, we aim to unveil the nuances of each architecture's capacity to harmonise the complex interplay of data within the evolving energy and E-mobility landscape. This study lays the groundwork for understanding how these architectures can empower stakeholders to navigate the challenges and opportunities presented by the data-driven transformation of the sector.

3.1. International Data Space Reference Architecture and Governance

The International Data Spaces Association (IDSA) is a non-profit organisation committed to advancing the IDS-Reference Architecture Model (IDS-RAM) as a global standard for secure and trusted data exchange within business ecosystems through five layers as shown in Figure 6 [42]. IDS-RAM identifies and discusses the strategic requirements necessary to enable entities to autonomously manage their data.

- **Trust Establishment:** Trust serves as the foundational pillar of the IDSA which is maintained through the IDS-RAM, where each participant undergoes a comprehensive evaluation and certification process, ensuring a thorough assessment of their credentials before being granted access to the esteemed and trusted business ecosystem facilitated by IDSA-RAM. This stringent approach to trust establishment is integral to ensuring reliable data exchange within the framework.
- **Data Security:** Data security is a fundamental requirement that must be ensured for participants within the IDS-RAM framework. This is achieved through the implementation of state-of-the-art security measures, involving an evaluation and certification process for each technical component utilised in the IDS. To further reinforce the central tenet of data security, a data owner in the IDS-RAM incorporates usage restriction information into their data before transferring it to a data consumer. Notably, for data utilisation, the data consumer is required to fully accept the data owner's specified usage policy. This

Funded by the European Union

approach establishes a high level of technical assurance in securing data integrity and confidentiality within the IDS-RAM ecosystem.

- **Decentralised Data Ecosystem:** The IDS-RAM framework adopts a decentralised approach to ensure that data is physically retained by the respective data owner until a transfer to a trusted party occurs. The IDS-RAM facilitates this process by providing detailed descriptions for each data source, including information about the value and usability of the data for other entities. Moreover, it offers the capability to integrate domain-specific data vocabularies, thereby empowering data owners to maintain control over their data while still facilitating seamless sharing with trusted parties.

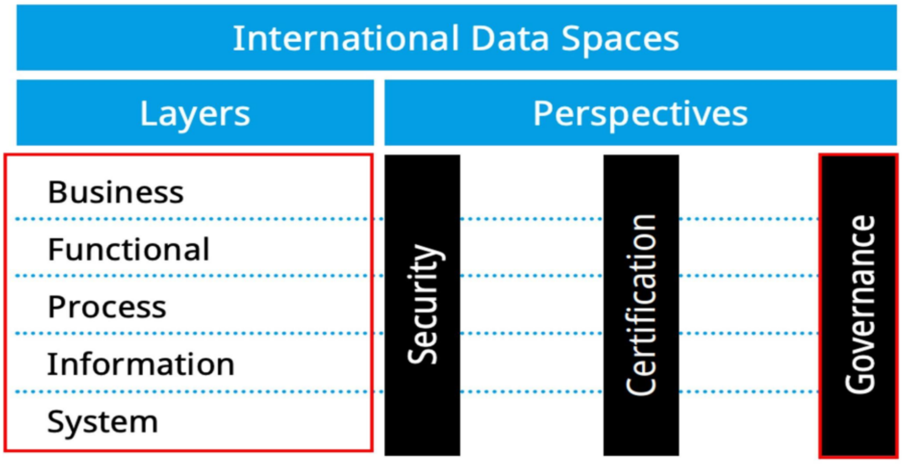

Figure 6. IDSA reference architecture for the data space highlighting the five layers with data security, trust, and governance Perspectives [42].

The governance perspective of the IDSA defines the requirements that must be met to achieve secure, reliable, and interoperable data exchange among the participating stakeholders in the data space. Consequently, these requirements encompass roles, functions, and processes on each layer of the reference model, as discussed below.

- **Business Layer:** The business layer delineates roles, data ownership, data provision, and data consumption. It also articulates core service concepts, such as data brokerage within the IDS, facilitating the development and utilisation of new digital business models by participants in the International Data Spaces.
- **Functional Layer:** The functional layer outlines the functional requirements of the IDS and introduces connectors as the primary interface enabling participants in the ecosystem. Additionally, it details interoperability and connectivity to ensure trust, security, and data sovereignty. The layer also highlights the functionality of specific core technical components, such as the App store related to the clearing house and identity providers in the context of the data governance perspective.
- **Process Layer:** The process layer delineates the interactions occurring between different components of the IDS by presenting key processes, including data publishing and exchange. It involves the use of data apps related to data governance, thus defining the scope of the technical architecture.

Funded by the European Union

- **Information Layer:** The information layer establishes a framework for standardised collaboration by offering a common vocabulary for Participants to express their concepts. This vocabulary is utilised within the IDS infrastructure for establishing individual agreements and contracts. It describes the data through metadata and plays a key role in data governance.
- **System Layer:** The system layer supports the data governance perspective by providing a technical implementation of different security levels for data exchange among stakeholders representing the data endpoints in the IDS.

The IDS Data Governance Model establishes a framework for decision-making rights and processes related to data definition, creation, processing, and usage. This is presented in the Responsibility Assignment Matrix (RACI matrix) in Table 3. RACI denotes "Responsible," "Accountable," "Consulted," and "Informed," with a focus on the "R" and "A" aspects, complemented by the notation "S" for "Supported."

Figure 3. Data governance for RACI matrix highlighting the responsibility, accountability, and support for the different IDS elements [42]

Activities	Governance Element	Data Owner/Providers	Data Consumer	Broker	clearing House
Data Usage Restrictions	Management	R, A	-	S	-
Enforce Data Usage Restrictions		-	R, A	-	-
Data Quality		R, A	-	S	-
Monitor Transactions		-	R, A	-	-
Data Provenance		S	S	-	R, A
Clearing Services		S	S	-	R, A
Publish Metadata	Meta Data	R, A	-	S	-
Lookup Metadata		-	R, A	S	-
Capture/Create Data	Data Lifecycle	R, A	-	-	-
Store Data		R, A	S	-	-
Aggregate Data		S	R, A	S	-
Distribute Data		R, A	-	S	-
Link Data		S	S	R, A	-

* Note: R: Responsible, A: Accountable, S: Supporting.

Funded by the European Union

3.2. Interoperable pan-European Grid Services Data Space Architecture

The Interoperable pan-European Grid Services Architecture (IEGSA) aims to facilitate the interface between the power system (TSO & DSO) and customers. This is achieved through the coordinated operation of all participating stakeholders under the EU Horizon-2020 funded INTERFACE project [43]. A detailed data exchange IEGSA architecture is presented in Figure 7 [44].

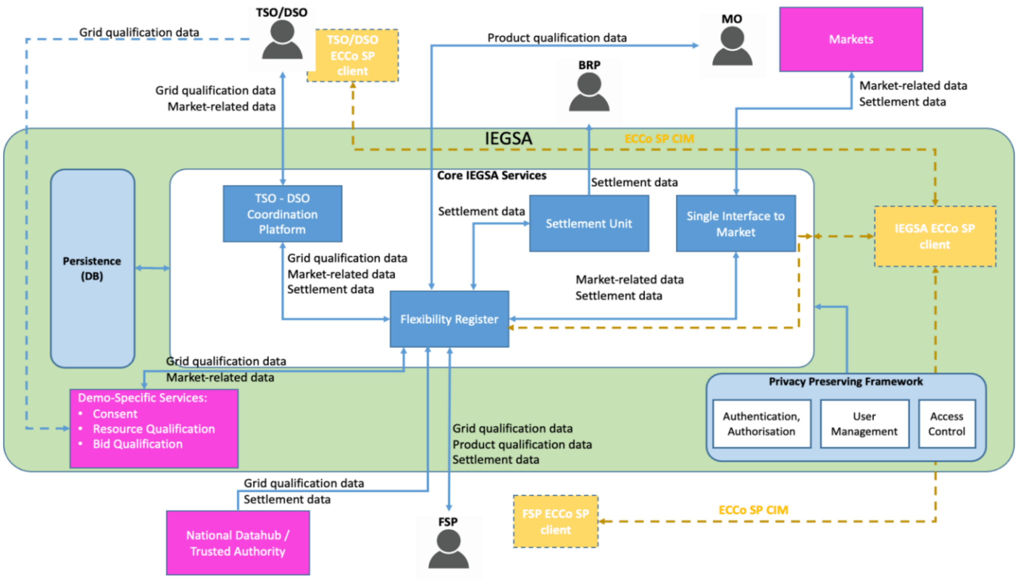

Figure 7. IEGSA reference architecture for the data exchange among the various participating stakeholders [44].

The IEGSA deliverable 9.14 discusses the data interoperability and data access framework, considering high-ambitious and low-ambitious scenarios. This analysis involves stakeholder dialogue, standardisation, and the EU entity for interoperability management. The following sections elaborate on these two scenarios, and a comprehensive data governance recommendation is presented in Table 4.

- In a high-ambition scenario, the European Commission could formally mandate participating entities to engage in standardisation activities aligned with their designated tasks and responsibilities. Besides standardisation, there might be future considerations for formal requirements, compelling European associations to contribute to interoperability testing and profiling.
- In a less ambitious scenario, the European Commission has the option to incorporate customer data exchange and access into the annual Union work program on European standardisation. It may then task one or multiple European Standards Organisations (ESOs) to develop an applicable European standard or deliverable related to European standardisation. An instance of an identified gap in standardisation pertains to managing customer consent and authentication.

Funded by the European Union

Table 4. IEGSA framework recommendation for the cross-sectional interoperability and data access [45]

Scenarios	Stakeholder dialogue (existing)	European standardisation	EU entity for interoperability management
High ambition	Set up an interoperability stakeholder committee	Require power system entities to contribute to standardisation activities, including testing and profiling	Set up an EU entity for interoperability management with three groups of tasks: (1) formalisation of best practices, (2) implementation monitoring and reporting, (3) interoperability testing
Low ambition	Renew the mandate of the EU smart grid task force (ESGTF)	integrate customer data exchange and access into the annual Union standardisation work programme	-

3.3. The EU-SysFlex Data Space Architecture and Governance

The EU-SysFlex is an EU Horizon 2020 funded project aimed at identifying issues and solutions related to integrating large-scale renewable energy. Its goal is to develop a plan that offers practical assistance to power system operators across Europe. Work Package 5, titled "Data Management for Facilitation of New Flexibility Solutions," is dedicated to data management and interoperability. It provides a conceptual model for data exchange, facilitating data governance across various layers and platforms, as illustrated in Figure 8 [46].

Funded by the European Union

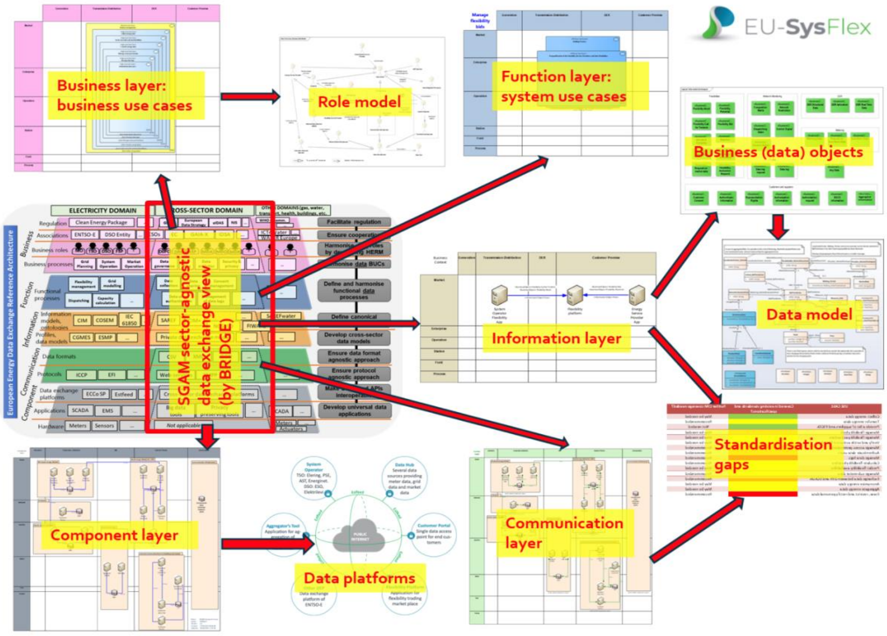

Figure 8. EU-SysFlex reference architecture for data exchange and governance across difference layers and platform [46].

The EU-SysFlex provides a data exchange platform for the pan-European electricity system, which includes descriptions of functionalities, processes, roles, and services, enabling interoperability among diverse platforms across Europe. The study of data governance for energy data collection, access, and processing focuses on perspectives from both the Data Exchange Platform (DEP) and the Data Hub, as discussed in the following.

- The Data Exchange Platform (DEP) functions as a communication platform facilitating secure data transfer from energy data providers, including data hubs, flexibility service providers, TSOs, and DSOs, to data consumers like TSOs, DSOs, consumers, suppliers, and energy service providers. The DEP stores encrypted services, such as the cryptographic hash of the requested data, and does not retain core energy data (e.g., metre data, grid data, market data). Meanwhile, these specific data types can be stored by data hubs.
- The data hub provides an information system that supports the storage and provision of various measurement data related to energy. This includes metre and operational data, along with other associated data.

To enhance data governance, deliverable 5.1.3 conducted interviews with Danish, Dutch, Italian, Belgian, and Estonian partners, focusing on key aspects related to DEP and Data Hubs. The interviews primarily addressed essential elements such as: Governance structures of the data platforms, Prioritised principles guiding energy data exchange, Data access and stakeholders benefiting from the data platform. Taking these factors into account, the report details data owners, operators, data types, facilitates market access, allows applications, and grants customer access rights. The findings of the report are summarised in Table 5, outlining their data governance approach [47].

Funded by
the European Union

Table 5. Summary of EU-SysFlex data governance framework for their various partners in different EU countries [47]

Country	Data Platform Ownership	Data Platform Operators	Data Type	Facilitate Market	App External Access	Customer Access
Netherlands	TSOs & DSOs	Grid own companies	Retail	No	No	No
Estonia	TSO	TSO	Both**	Yes	Yes	Yes
Italy	The state	Third party	Both	No	No	No
Belgium	5 DSOs	Atrias**	Retail	Planned	No	Planned
Denmark	TSO	TSO	Retail	No	Yes	Yes
Sweden	TSO	TSO	Retail	No	Yes	Yes
Finland	TSO	TSO	Retail	No	Yes	Yes
Norway	TSO	Subsidiary of TSO	Retail	No	No	Yes

* Both includes the wholesale and retail data; ** Atrias is a private company

3.4. FlexiGrid Data Space Architecture and Governance

The FlexiGrid project, funded by EU-Horizon 2020, seeks to create an enabling architecture for small and medium-sized DSOs. The primary goal is to unleash flexibility resources by integrating and optimising resources across different energy vectors, emphasising the coupling of sectors. This includes optimising demand response through EV charging schemes or storage utilisation. By doing so, DSOs can address future capacity shortages with flexibility and modernise outdated systems with smart technology. To achieve optimisation across EU member states, the project aims to deliver IoT platforms, peer-to-peer and peer-to-pool marketplaces, vehicles-to-grid, power-to-heat, and power-to-gas solutions. Additionally, the project explores innovative business models to support data exchange and governance across the participating stakeholders as shown in Figure 9 [48].

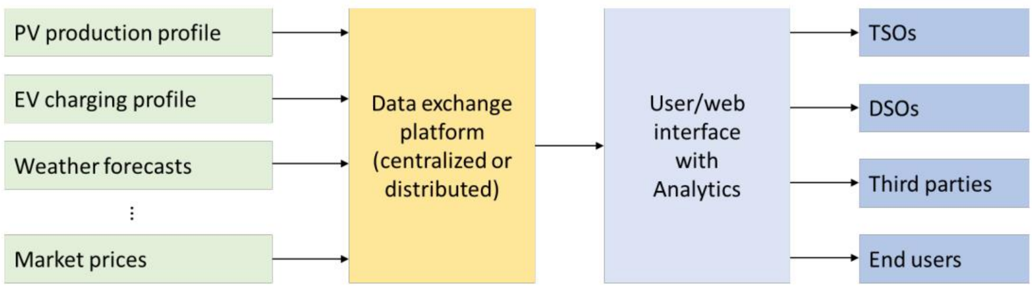

Figure 9. Data exchange framework in the FlexiGrid architecture: Emphasising centralised/decentralised platforms accessible via web interface [48].

The report presented two types of power system data: operational and non-operational. Operational data encompasses parameters related to network operation (e.g., voltage magnitude, voltage angle, power flow), collectible through advanced metering infrastructure (AMI), phase measurement unit (PMU), or supervisory control and data acquisition (SCADA)

Funded by the European Union

systems. On the other hand, non-operational data supports network operators in operation, management, and control, incorporating weather data, electricity market data, customer behaviour data, etc. Following these data types, the report discusses data governance, focusing on privacy, security, and transparency, as summarised in Table 6 [48].

Table 6. A summary of the FlexiGrid data governance for the operational and non-operational data [48]

Data	Data type	Governance type	Access Permission
Personal data	Non-operational	Privacy	Utility operators
Metre data	Non-operational	Privacy	Utility operators
Voltage data	Operational	Security	TSO, DSO
Current flow data	Operational	Security	TSO, DSO
Power quality,	Operational	Security	TSO, DSO
Fault detection data	Operational	Security	TSO, DSO
Historical DER data	Non-operational	Transparency	TSO, DSO, Utility operators
Load estimation data	Non-operaitonal	Transparency	TSO, DSO, Utility operators, aggregators, Users
Electric price data	Non-operational	Transparency	TSO, DSO, Utility operators, aggregators, and Users
Generation capability	Non-operational	Transparency	TSO, DSO, Utility operators

3.5. Platoon Energy System Data Space and Governance

The Digital Platform and Analytic Tools for Energy (Platoon) is an EU-funded Horizon 2020 project with the objective of digitising the energy sector [49]. This is achieved through the implementation of distributed edge processing and data analytics technologies, facilitating optimised real-time management of energy systems. The project also places a strong emphasis on ensuring robust data governance among diverse participating stakeholders. To enable multi-party data exchange, Platoon employs connectors based on the IDS framework. PLATOON has introduced a flexible and modular lightweight reference architecture designed for data exchange and governance among diverse stakeholders within the energy system, as illustrated in Figure 9 [49]. This reference architecture prioritises interoperability, relying on open APIs and data models to facilitate effective data exchange. Additionally, the architecture places a strong emphasis on data governance, utilising the IDS framework to ensure agreements for shared data.

Funded by the European Union

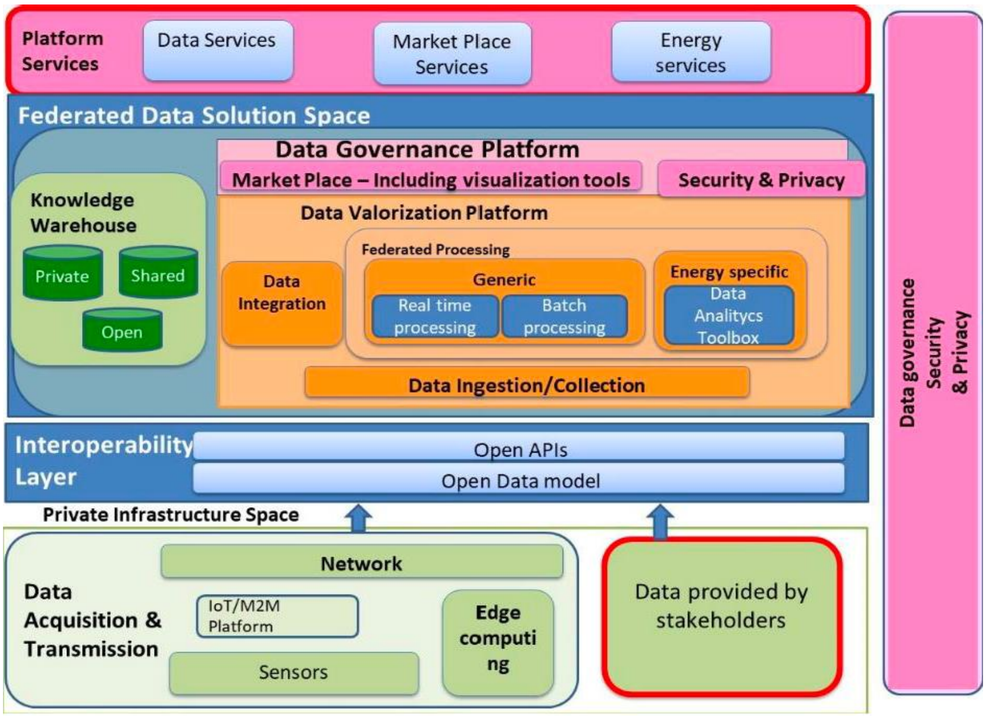

Figure 10. PLATOON reference architecture for the data exchange and governance, highlighting the interoperability layer based on open API's and data governance based on IDS [49].

Deliverable 3.1 focuses on data governance, security, and privacy requirements for the energy sector. It highlights three key data players, identifies the main barriers in data exchange, and outlines requirements for data security, access, usage, and governance, as discussed in the following [49].

3.5.1. Data Players

Three distinct types of business roles are identified and discussed in the following.

- **Data Providers:** In the energy sector, data suppliers refer to organisations that either generate data with intrinsic value, making it marketable, or serve a brokerage role by providing access to aggregated first- and third-party data. These organisations play a crucial role in contributing valuable information for various applications within the energy ecosystem.
- **Data Facilitators:** The data facilitators refer to entities that provide support to third parties lacking the necessary infrastructure or expertise in handling data. These facilitators offer a spectrum of services, including guidance on leveraging big data, supplying physical infrastructure, and offering outsourced analytics services.
- **Data users:** data users refer to organisations/customers that leverage data for various purposes, either to inform their business decisions or as an input into other products and services. These entities play a crucial role in extracting meaningful insights from the

Funded by the European Union

available data to enhance operational efficiency, optimise resource utilisation, and support informed decision-making.

3.5.2. Barriers in Data Exchange

There are technical and legal compliance challenges that pose obstacles to participants in data sharing and exchanging, as highlighted by the PLATOON deliverable 3.1. These challenges are summarised in the following Table 7.

Table 7. A summary of the technical and legal compliance barriers associated with the data exchange identified by the PLATOON deliverable 3.1 [49].

Barrier	Description
Managing sensitive data according to GDPR	All stakeholders are required to manage and distribute sensitive information, particularly within the context of the smart grid, in a manner that aligns with GDPR principles. These principles place restrictions on the capture, storage, and distribution processes.
Managing data ownership	Marketplaces depend on the transferable ownership of data, necessitating exploration into different ownership models or the development of suitable data rights management frameworks.
Verification and provenance	Ensuring the accuracy and traceability of data is essential, necessitating the implementation of advanced provenance mechanisms.
Security and restriction on Data access and storage	Ensuring a trusted network involves implementing secure access controls, standardised security solutions, and adherence to GDPR principles, including the minimisation of data storage. In real energy projects, mechanisms must be in place for end users to easily request the application of their rights without compromising system integrity.
Maturity of privacy-preserving technologies	While secure and trustworthy data sharing solutions are currently available and continuously evolving, there is a need to explore more flexible approaches to enhance their adoption.
Data Flow Legal Constraints	Free data flow across Europe faces legal challenges related to data ownership, access, portability, retention, etc., necessitating further exploration and resolution of these legal matters.
Data Policy Uncertainty	Insufficient regulation hampers development and necessitates exploration of strategies for incorporating and adapting to the regulatory landscape within the Digital Single Market, particularly in the energy sector.
Lack of Unified Data Management Strategy	The message-based data management model involves accessing a raw physical data repository through specific data services, enabling other processes and services to query for specific pieces of information. In contrast, the shared database model features a unique data repository where both ends exchange information, allowing for the reading and writing of the same resource. Each model presents distinct approaches to data interaction and exchange within a system.

Funded by the European Union

3.5.3. Data Governance Recommendations

Data governance involves making decisions about data management to ensure the safe, fair, and secure handling of data within and across a network of nodes in the energy data space. This network facilitates the passage of data to fulfil pre-identified data value chains. Table 8 presents a concise summary of data governance recommendations for the PLATOON framework, focusing on aspects such as data security, access, usage control, and privacy [49].

Table 8. Data governance recommendation of PLATOON in terms of data security, access control, usage control, and privacy [49].

Data Governance Terms	PLATOON Framework Recommendation
Data Security	● Symmetric Encryption: Utilise AES-128, AES-192, or AES-256, preferably in GCM mode or EAX mode. ● Asymmetric Encryption: Choose from ECIES-250 (384 bits or more), DLIES-2000 (3072 bits or more), RSA 2000 (3072 bits or more), curve25519, curve448, or ECC Brain pool. ● Hash Functions: Implement SHA-256, SHA-384, SHA-512, SHA3-256, SHA3-384, and SHA3-512. ● Key Derivation Functions (KDF) and Password Hashes: Opt for Argon2, PBKDF2, scrypt, and bcrypt. ● Transport Layer Security: Use TLS 1.3 with forward secrecy for secure communication.
Access Control	● Authorization: Access Control List (ACL), Role Based Access Control (RBAC), Attribute Based Access Control (ABAC) ● Authentication: Role-Based Access Control (RBAC), API Key Authentication, JSON Web Tokens (JWT), and Client Certificates
Usage Control	● Intellectual Property Protection: Implementing robust usage control mechanisms, access policies, and encryption safeguards intellectual property, ensuring protection against unauthorised copying, distribution, or modification of proprietary data. ● Compliance with Regulations: Ensuring strict adherence to data protection regulations, industry standards, and legal frameworks through fine-grained access controls, regular audits, and monitoring activities to demonstrate and address compliance promptly. ● Digital Rights Management (DRM): Deploying a comprehensive DRM strategy involving encryption, licensing, and access policies to manage rights, permissions, and secure traceable access to sensitive digital assets. ● Audit and Monitoring: Establishing a robust auditing mechanism to track and record data usage activities, monitoring user interactions for identifying and mitigating potential security threats and integrating real-time alerts for

Funded by the European Union

	suspicious behaviour.
Privacy	● Lawfulness, Fairness, and Transparency: The principle of lawfulness, fairness, and transparency mandates data processing in compliance with legal requirements, ensuring individuals are transparently informed about the purposes, fostering trust and informed decision-making. ● Purpose Limitation: requires organisations to communicate specific, legitimate data processing purposes to individuals at collection, preventing unauthorised use and fostering trust through transparent communication. ● Data Minimisation dictates organisations collect and process only essential data for specified purposes, promoting efficiency, limiting personal information scope, and mitigating risks associated with unnecessary processing. ● Integrity and Confidentiality, crucial in GDPR, mandate organisations to employ robust security measures, including encryption, ensuring personal data's confidentiality, and preventing unauthorised alterations for maintaining reliability and trustworthiness.

3.6. SYNERGY Data Space Architecture and Governance

SYNERGY is an EU Horizon 2020 project with the goal of developing a Big Energy Data Platform and Analytics Marketplace [50]. This initiative includes the development of domain-specific applications leveraging big data to empower stakeholders across the electricity value chain. The primary objectives are to extend data accessibility, enhance internal intelligence, optimise operations, and foster participation in innovative business ecosystems through data sharing and trading.

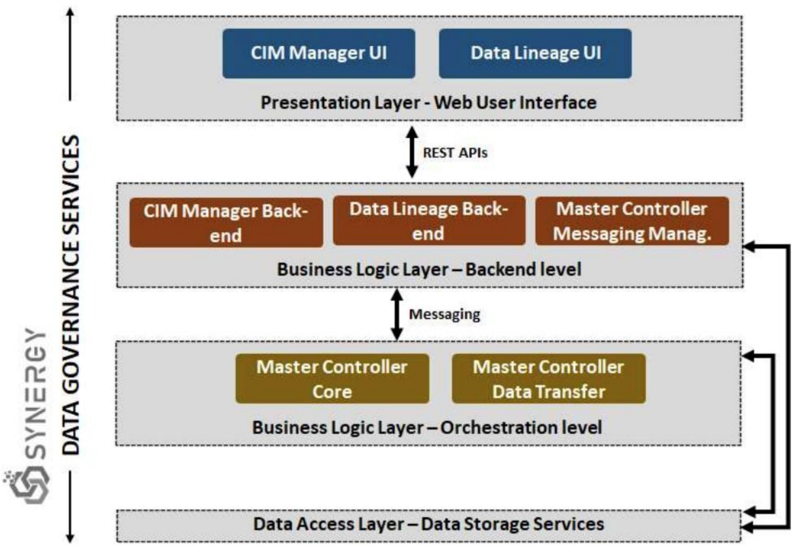

Figure 11. The SYNERGY project layered reference architecture for data governance services [51].

Funded by the European Union

SYNERGY deliverable 3.2 presents a detailed data governance architecture and discusses data collection, security, storage, governance, and management services, as shown in Figure 11 [51]. The figure illustrates the referenced data governance architecture, outlining three primary functional components, as discussed below.

- *Master Controller (MC):* The MC plays a pivotal role in orchestrating services within the SYNERGY Core Cloud Platform, Secure Experimentation Playgrounds, and On-Premises Environments. It operates based on user configurations, whether they are data asset providers or consumers. The MC is also tasked with automatically scheduling data check-in and analytics services, adhering to users defined scheduling configurations.
- *Data Lineage Service (DLS):* The Data Lineage Service plays a critical role in upholding data integrity by managing and tracing all changes or actions made to a data asset, encompassing alterations to its content, structure, or metadata. This service records the evolution of a data asset and its relationships with other data assets. Authorised users can leverage this information to identify and address potential issues associated with the data asset.
- *Common Information Model (CIM):* The CIM manager holds the crucial responsibility of overseeing the lifecycle of the Common Information Model. This involves managing domain-specific information integral to the exchange of data among stakeholders in the electricity data value chain. The CIM manager is involved in tasks such as creation, validation, updating, and deprecation of the CIM. This ensures that the model is consistently enriched and updated by the model administrator, maintaining its usability and sustainability across various functionalities provided by the SYNERGY Platform.

The data services and the recommendation of the SYNERGY pertaining to data collection, data collection, security, storage, and governance is summarised in Table 9 [51].

Table 9. A summary of the SYNERGY functionalities for the different data services pertaining to data collection, security, storage, and governance [51].

Data Service Name	SYNERGY Platform Functionalities
Data Collection	Data collections functionalities includes: ● Data Handling Manager ● Matching Prediction Engine ● Data Ingestion Service ● Mapping & Transformation Service ● Cleaning Service
Data Security	Data security functionality includes: ● Anonymisation Service ● Encryption Engine ● Access Policy Engine
Data Storage	Data storage functionalities includes: ● Permanent storage of processed datasets in a scalable database. ● Metadata storage for dataset information and relevant connections.

Funded by the European Union

	• Storage for analytics models, including pre-trained algorithms. • Configuration storage for data check-in and analysis job settings. • Temporary object storage for intermediate and uploaded files. • Secure storage for sensitive data and credentials. • Storage for SYNERGY CIM concepts and energy vocabularies. • Distributed ledger storage for smart data asset sharing contracts, ensuring non-repudiation, traceability, and privacy
Data Governance	Data governance functionalities includes: • Master Controller • Data Lineage Service • Common Interface Manager

3.7. OneNet Data Space Architecture and Governance

The OneNet project, funded by EU-Horizon2020, aims to establish a unified platform facilitating the optimisation of power system networks and comprehensive energy management for near-real-time integration of all stakeholders [52]. Adopting a customer-centric approach to grid operation, OneNet strives to create favourable conditions for a new era of grid services, maximising the potential of demand response, storage, and distributed generation. The project is dedicated to fostering fairness, transparency, and openness in consumer interactions. The main functional components of the reference architecture are presented in the following.

- The bottom layer encompasses both data sources and energy stakeholders, constituting the OneNet participants.
- The middle layer, within the OneNet ecosystem, facilitates the establishment of OneNet Network of Platforms. It encompasses all platforms engaged in data exchange and the utilisation of cross-platform services.
- The uppermost layer, aptly designated the OneNet Framework, serves as the nucleus of the OneNet Architecture, which encompasses essential specifications for data standardisation, ontologies, data modelling, service orchestration, workflow monitoring, analytics etc.

The OneNet data governance framework establishes a comprehensive set of rules and processes for the collection, storage, and utilisation of data. This framework is designed to enhance and expand essential governance processes, ensuring the meticulous oversight of key aspects associated with data processing, including data quality, ownership access, and the efficacy of platforms employed for data processing, as illustrated in Figure 12 [53]. The figure highlights five key dimensions to streamline the data governance framework, as presented in the following. The OneNet data governance functionalities for the five data dimensions are summarised in the following Table 10.

Funded by the European Union

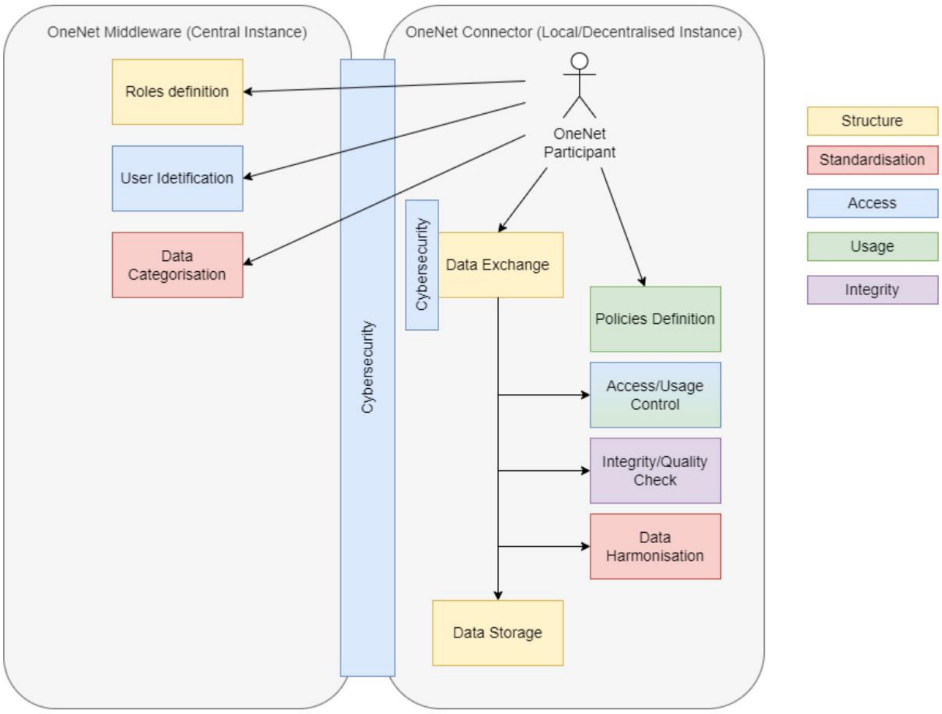

Figure 12. OneNet Reference Architecture, highlighting five key dimensions of data governance [53].

Table 9. A summary of the SYNERGY functionalities for the different data services pertaining to data collection, security, storage, and governance [53].

Data Dimensions	OneNet Data Governance Services
Structure	OneNet's structural approach defines middleware and connectors that centrally store metadata and facilitate data exchange among participating stakeholders, ensuring seamless data integration across platforms.
Standardisation	OneNet supports over 60 cross-platform services in 10 categories, each with defined data formats/models for seamless integration, portability, reusability, and interoperability. The system includes a data harmonisation tool mapping CIM standards from XML to JSON-LD for NGSI-LD compatibility.
Access	OneNet participants, serving as Data Providers or Consumers, set access policies for data exchange. The Identity Manager in OneNet Middleware ensures participant identification, fostering a trusted data space. A dedicated security layer guarantees authentication and authorisation within the OneNet ecosystem.
Usage	OneNet enhances access management with IDS-inspired usage control, specifying and enforcing data-related restrictions for intellectual property protection, regulatory compliance, and digital rights management. Implemented at the OneNet Connector level, the Usage Control App automates this process, focusing on data processing requirements rather than access provisioning.
Integrity	OneNet ensures data integrity by utilising the FIWARE Context Broker

Funded by the European Union

	and NGSI-LD standard for formatting and processing exchanged data. This standardisation allows for standardised verification of data correctness and quality. The Cybersecurity Layer, employing OAuth2.0 tokens and AI-driven mechanisms, plays a pivotal role in securing end-to-end data exchange, monitoring traffic, logs, events, and identifying potential cyberthreats.

4. Semantic-Web based E-Mobility Data Space and Governance

E-mobility signifies a transformative convergence of the energy system and the mobility sector, transitioning from traditional internal combustion engines to EVs. This shift is driven by a shared commitment to reduce carbon emissions, enhance energy efficiency, and promote sustainability in transportation. E-mobility integrates advanced technologies, primarily focused on the electrification of vehicles, including electric cars, buses, and bikes, powered by electricity stored in batteries. There are various stakeholders involved, such as utility companies, charging station operators, and E-mobility service providers, that collaborate to establish charging networks, optimise fleet management, and elevate user experiences. Electric vehicle manufacturers contribute significantly to the technological advancements shaping EV design and performance. Government and regulatory bodies play a pivotal role in guiding E-mobility practices, setting standards, and providing incentives for sustainable transportation. Within this dynamic landscape, the chapter identifies key players, delineates their roles, explores associated data, and employs semantic web ontologies to develop a comprehensive data space and data governance framework tailored for the specific requirements of E-mobility. This FLOW framework aims to address the diverse data needs of stakeholders, fostering seamless integration, data quality, and adherence to privacy and security standards within the E-mobility ecosystem.

4.1. Stakeholders in E-Mobility

In the development of the E-mobility data space, it is imperative to identify the diverse stakeholders, outline their roles, and delineate their data generation and utilisation needs [54]. This section delves into an exploration of the different stakeholders, elucidating their respective roles in the context of data and articulating the specific requirements they have in terms of data generation and utilisation.

4.1.1. Power Grid System

Power grids provide the essential infrastructure to meet the rising demand for electricity and serve as the backbone for E-mobility. The significance lies in their capacity to handle the specific requirements of EVs and charging stations. Smart grids and advanced energy management systems play a crucial role in this context, optimising the charging processes and efficiently distributing power. The power grid generates substantial data related to electricity consumption patterns, demand fluctuations, and charging station usage. This data is invaluable for

Funded by the European Union

understanding and predicting energy needs, facilitating strategic planning, and enhancing the overall efficiency of the grid. Additionally, smart grids enable real-time monitoring and control, ensuring a seamless integration of EVs into the energy ecosystem.

In turn, the power grid relies on data from various stakeholders involved in E-mobility. Charging station operators provide information about the availability, usage, and health of charging infrastructure. Utility companies contribute data on grid capacity, electricity pricing, and demand forecasting. E-mobility service providers offer insights into user behaviours, charging preferences, and fleet management requirements. This collaborative exchange of data among stakeholders, facilitated by the power grid, is fundamental for creating a responsive and sustainable E-mobility ecosystem. It allows for informed decision-making, optimal resource allocation, and the development of innovative solutions to address the evolving challenges in the intersection of energy and transportation.

4.1.2. Transmission System Operators

Transmission service operators play a pivotal role in the energy sector by managing the high-voltage transmission infrastructure that transports electricity from power generation facilities to the distribution networks. Their primary responsibility is to ensure the reliable and efficient transmission of energy across long distances. To ensure smooth operations of the transmission network the TSO incentivizes energy aggregators, utility companies, and electric vehicle fleet operators to optimise their load and reduce peak demand, transmission service operators engage in demand-side management initiatives. By providing incentives, they encourage these entities to adjust their energy consumption patterns strategically. This may involve shifting energy-intensive activities to off-peak hours, utilising energy storage solutions, or adopting load management practices. The data generated by transmission service operators includes real-time information on grid performance, transmission line capacities, and overall system load. They also rely on historical consumption data and forecasts to anticipate peak demand periods. Utilising this data, transmission service operators can optimise the allocation of transmission resources, improve grid reliability, and foster a more balanced and efficient use of energy resources across the distribution network. Incentivising load optimization contributes to a more sustainable and resilient energy infrastructure, aligning with broader goals of energy efficiency and environmental sustainability.

4.1.3. Distribution System Operators

Distribution System Operators manage the lower-voltage distribution networks that deliver electricity directly to end-users, including energy aggregators, utility companies, and electric vehicle fleet operators. The primary responsibility of DSOs is to ensure the reliable and safe distribution of electricity from the higher-voltage transmission system to homes, businesses, and other consumers. DSOs facilitate the connection of various energy sources to the grid and coordinate the distribution of power across their networks. The DSOs collaborate with the energy aggregators, utility companies, and electric vehicle fleet operators, to optimise the distribution of electricity, balancing supply, and demand. This involves integrating renewable energy sources,

Funded by the European Union

managing grid constraints, and supporting the integration of electric vehicles into the network. The data generated by DSOs includes information on local grid conditions, voltage levels, and equipment health. They also utilise data on consumption patterns, demand forecasts, and real-time monitoring to efficiently allocate resources, plan for grid upgrades, and ensure a resilient and responsive distribution system. By leveraging this data, DSOs contribute to the effective integration of diverse energy sources and the promotion of a more sustainable and reliable energy infrastructure.

4.1.4. Utility company

Electric utility companies serve a critical role in the energy sector, acting as intermediaries between electricity producers and retail consumers. In the process of buying energy from the grid and selling it to the retail market, these companies acquire electricity from diverse sources, including power plants using fossil fuels, renewables, and nuclear energy. Procurement is often done through energy markets and contracts. Subsequently, the utility companies distribute electricity through their grid infrastructure to residential, commercial, and industrial customers, billing them based on individual consumption. The types of data generated in this process include information on grid performance, electricity consumption patterns, market dynamics, and billing records. Utility companies utilise this data for load forecasting, market analysis, grid optimisation, accurate customer billing, and regulatory compliance. By leveraging these insights, utility companies play a vital role in ensuring a reliable and efficient electricity supply to meet the demands of the retail market.

4.1.5. Charging Station Operators

Charging Station Operators (CSOs) are pivotal in the E-mobility landscape, overseeing the deployment and management of charging infrastructure for EVs. They strategically plan the placement of charging stations based on data related to traffic patterns, population density, and EV adoption rates. Operational monitoring is a key aspect, involving real-time tracking of charging station usage, availability, and maintenance needs. CSOs facilitate a seamless user experience by managing payment and billing processes, collecting user feedback, and ensuring the interoperability of charging networks. Collaboration with utility companies is essential, as CSOs use grid load data to optimise charging schedules and implement smart charging solutions. Moreover, they rely on market trends and regulatory data to plan network expansions and ensure compliance with regional policies. The comprehensive data generated and utilised by Charging Station Operators covers operational efficiency, user satisfaction, grid integration, and regulatory adherence, contributing significantly to the growth and sustainability of electric mobility ecosystems.

4.1.6. Charging Station

Charging stations in E-mobility generate critical data to facilitate seamless charging experiences and optimise operational efficiency. This includes charging session details such as start and end

Funded by the European Union

times, energy consumption, and rates, along with user-specific information for personalised services and access control. Payment transaction records ensure accurate billing, while real-time operational status data helps address maintenance needs promptly. Location and geospatial information aid in both user navigation and strategic planning for optimal station placement. Additionally, charging stations leverage power distribution data to interact efficiently with the electrical grid, contributing to effective grid management. The utilisation of this diverse data landscape enables charging stations to enhance user experiences, ensure financial reliability, integrate with the grid intelligently, and plan for future expansions strategically, collectively supporting the growth and sustainability of electric mobility ecosystems.

4.1.7. E-Mobility Service Providers

E-Mobility Service Providers (EMSPs) actively generate and leverage diverse datasets to ensure the smooth functioning of electric mobility services. They generate user-specific data encompassing account details, preferences, and authentication information. Charging session data, including information on start and end times, energy consumption, and rates, is crucial for users to track their charging history. Geospatial data aids in the location of charging stations and strategic infrastructure planning. Real-time operational status data on charging stations' availability, maintenance requirements, and technical issues facilitates efficient service management. Payment transaction records are essential for accurate billing and financial transparency. EMSPs utilise this data to enhance user experiences, optimise operational efficiency, and plan for future infrastructure expansion. By analysing user behaviour, charging patterns, and market dynamics, they can refine marketing strategies, contribute to grid integration, and ensure the growth and sustainability of the electric mobility ecosystem.

4.1.8. Fleet Operators

Fleet operators in E-mobility generate and leverage a diverse array of data to effectively manage their EV fleets. This includes real-time vehicle telemetry data, charging session details, and maintenance and diagnostics information, allowing operators to monitor fleet movements, optimise charging behaviours, and implement proactive maintenance strategies. Driver behaviour data, encompassing driving patterns and habits, assists in evaluating and improving driver performance for enhanced safety and efficiency. Additionally, route and navigation data aids in optimising travel routes, reducing travel times, and strategically planning for optimal charging infrastructure locations. By analysing these datasets, fleet operators can optimise operational efficiency, manage energy consumption, evaluate driver performance, plan proactive maintenance, and make informed decisions regarding fleet expansion and overall cost management, contributing to the overall success and sustainability of their electric vehicle fleets.

4.1.9. Energy Aggregators

Energy aggregators in E-mobility are instrumental in managing and optimising the energy consumption of EVs, generating and utilising diverse datasets. They generate aggregated charging

Funded by the European Union

session data, including start and end times, energy consumption, and charging rates across multiple EVs, offering insights into comprehensive energy demand patterns. Load forecasting data enables these aggregators to predict future demand, facilitating proactive energy management and grid interactions. With access to demand response information, they can adjust charging schedules during periods of high or low electricity demand, contributing to grid stability. Utilising real-time grid integration data, energy aggregators make informed decisions for smart charging, optimising charging schedules based on factors like electricity prices and the availability of renewable energy. In essence, these aggregators play a pivotal role in balancing energy demand, optimising procurement strategies, participating in demand response programs, and supporting a resilient and sustainable E-mobility ecosystem.

4.1.10. Electric Vehicles

Electric vehicles in E-mobility generate and utilise diverse datasets to optimise performance and contribute to the overall efficiency of the electric mobility ecosystem. They generate real-time telemetry data, offering insights into speed, battery state of charge, energy consumption, and location. Charging session data provides details on start and end times, charging rates, and energy consumed, aiding users in monitoring and optimising charging habits. Battery health data informs users about the overall health and performance of the vehicle's battery, influencing maintenance needs and reliability. Driving behaviour data, encompassing driving patterns and energy usage, aids in optimising energy efficiency and range estimation. Electric vehicles utilise this data to optimise energy efficiency, estimate remaining range, plan charging behaviours, schedule maintenance, enhance user interfaces, and provide connected services. Overall, the data generated and utilised by electric vehicles plays a crucial role in improving performance, user experience, and the sustainability of E-mobility.

4.1.11. EV Owners

Electric vehicle owners in E-mobility actively generate and utilise diverse datasets to optimise their driving experience and charging habits. They generate charging session data, detailing start and end times, energy consumption, and charging rates, aiding in monitoring charging history and costs. Driving behaviour data, encompassing driving patterns and energy usage, allows users to adjust habits for improved range and overall efficiency. Real-time telemetry data on battery state of charge, range, and energy consumption provides insights into the vehicle's operational conditions. Location-based information, including trip history and routes taken, aids in travel pattern insights and route optimization. Maintenance data, such as service schedules and repairs, contributes to proactive vehicle care. EV owners utilise this data to optimise charging behaviours, monitor energy efficiency, estimate range, manage costs, plan maintenance, and enhance their overall driving experience, contributing to the successful integration and sustainability of electric mobility.

Funded by the European Union

4.2. Characterisation of Stakeholders Data Types

It is apparent that stakeholders in the E-mobility sector generate and utilise diverse data types, resulting in interdependencies in their operations [55]. In this section, we aim to characterise the participating stakeholders based on their data types, ownership, and the entities that leverage their data, as outlined in Table 10. The analysis underscores the intricate network of relationships shaped by the exchange and utilisation of data among these stakeholders.

Table 10. Characterisation of the different stakeholders and their data types in terms of ownership and utilisation.

Stakeholders	Data type	Data Ownership	Data Utilisation
Power Grid	Grid topology data, Energy flow data, Substation data, Outage data	Power Grid operator (TSOs & DSOs)	Utility companies, Energy Aggregators, E-mobility Operators, Fleet Operators, and Researchers
Transmission System Operators	High-voltage grid data, Power generation data, Transmission line capacity data, Inter-regional electricity market data	TSOs	DSOs (coordination), E-mobility operators (grid planning), Regulatory bodies
Distribution System Operators	Medium-voltage and low-voltage grid data, Local energy consumption data, Distribution transformer data, E-mobility charging data (detailed)	DSOs	DSOs (coordination), E-mobility operators (grid planning), Regulatory bodies
Utility Company	Customer data, Billing data, Metering data, Power quality data, E-mobility charging data (aggregated)	Utility company (Customer data with consent)	TSO (grid planning), DSO (distribution network management), E-mobility operators (anonymized data), Regulatory bodies
Energy Aggregator	Aggregated energy consumption data, Forecasted energy demand, Renewable energy production data, Electricity market data	Energy aggregator (Data purchased from utilities or power generators)	Utility companies, E-mobility operators, Power retailers
Charging Station	Location data, Power rating, Connector types, Real-time availability, Energy	Charging station operator, Electric vehicle user (limited data)	DSO (grid impact assessment), E-mobility operators, Utility companies, Electric vehicle users (app for station status)

Funded by the European Union

	dispensed data (anonymized)		
Charging Station Operator	Number of charging stations owned/managed, Station maintenance data, Network usage statistics, Customer data (station users)	Charging station operator	DSO (grid impact assessment), E-mobility operators (partnership agreements), Regulatory bodies
E-Mobility Operator	Electric vehicle user data (anonymized), Trip data (origin, destination, distance), Charging data (station ID, energy consumed, timestamp), Vehicle data (type, model, battery capacity)	E-mobility service provider, (Collected from users with consent), Electric vehicle users (app for trip data)	DSO (grid impact assessment), TSO (grid planning), Utility companies (charging data), PowerGrid operator (anonymized data for grid planning), Research institutions
Electric Vehicle	Vehicle identification data (VIN), Battery health data, Battery Capacity data, Battery, Energy consumption data, Location data (optional, with user consent)	Electric vehicle manufacturer, Electric vehicle user (through car infotainment system)	E-mobility operators (charging data), Repair shops (diagnostic data), Insurance companies (with user consent), Charging station operators, Fleet operators, Energy aggregators
Electric Vehicle User	Account information, Trip preferences, Charging preferences, Payment information	Electric vehicle user	E-mobility operators, Charging station operators (for station access), Third-party service providers (with user consent)

4.3. Data Governance Dimensions in E-Mobility

The intricate web of data sources within E-mobility demands a comprehensive data governance framework. Implementing robust data governance policies empowers stakeholders across the E-mobility ecosystem to ensure responsible data collection, usage, and protection. This fosters trust, transparency, and facilitates responsible data-driven decision-making, paving the way for a sustainable E-mobility future [56]. Leveraging a platform like FLOW, we identified several key data governance dimensions, as discussed in the following.

4.3.1. Access Control Policy

The Access Control Policy (ACP) in the E-mobility ecosystem is instrumental in regulating data access by defining who can access specific data types and the level of access granted,

Funded by the European Union

encompassing read-only, modify, or delete permissions. A key component of the ACP is the establishment of roles and permissions, delineating user roles such as system administrator, charging station operator, and electric vehicle user, with corresponding permissions specifying their data access and actions (view, edit, delete). The policy also addresses authentication and authorization methods, incorporating user identity verification through mechanisms like username/password logins, multi-factor authentication, or role-based access control (RBAC). Additionally, the ACP acknowledges data sensitivity, recognising that highly sensitive data, such as user location information, requires more stringent access controls compared to less sensitive data like charging station locations. By comprehensively addressing roles, authentication, authorization, and data sensitivity, the ACP ensures a robust and secure framework for managing data access within the E-mobility ecosystem.

4.3.2. Data Usage Policy

The Data Usage Policy (DUP) within the E-mobility ecosystem serves as a critical framework, stipulating the permissible applications of the collected data. With a focus on purpose limitation, the DUP precisely defines the authorised reasons for data collection and usage, explicitly prohibiting unauthorised use while ensuring adherence to user consent. For instance, it ensures that user location data collected for optimising charging station placement remains exclusively dedicated to that purpose and cannot be employed for targeted advertising without explicit user consent. The policy extends its purview to data sharing, articulating guidelines for interactions with third-party entities. This may involve implementing data anonymization techniques or secure data transfer protocols to secure user privacy during sharing activities. Additionally, the DUP establishes a clear demarcation between internal data usage for operational needs and external usage for research or service development. By incorporating these details, the DUP establishes a comprehensive and ethical foundation for the responsible use of data within the E-mobility ecosystem.

4.3.3. Data Retention Policy

The Data Retention Policy (DRP) dictates how long different data types within E-mobility must be retained. This balancing act considers legal requirements, business needs, and data sensitivity. For instance, critical infrastructure data like grid topology might require long-term storage for effective grid planning purposes. Conversely, anonymized charging session data, with less sensitivity, might have a shorter retention period based on business needs for service improvement or trend analysis. The DRP also outlines secure data disposal procedures after the designated retention period expires. This can involve data deletion, anonymization to further protect privacy, or secure data destruction methods to ensure sensitive information doesn't fall into the wrong hands. Finally, the DRP ensures adherence to relevant data retention laws and regulations, such as tax regulations or data privacy laws like GDPR, to maintain compliance and user trust.

Funded by the European Union

4.3.4. Data Privacy Policy

The Data Privacy Policy (DPP) fosters trust and transparency by informing users about data collection practices within the E-mobility ecosystem. This includes clearly outlining what data is collected (e.g., charging location with consent), how it's used (e.g., optimising charging station placement), and with whom it may be shared (anonymously for research purposes). The DPP emphasises obtaining user consent, ensuring it's freely given, informed about the specific data usage, and allows users to withdraw consent at any time. Furthermore, the DPP details user rights regarding their data, such as the right to access, rectify inaccurate information, or even request erasure of their data. It should also explain how users can exercise these rights through clear and accessible procedures. Finally, the DPP ensures compliance with relevant data privacy regulations, such as GDPR, to safeguard user privacy and build trust within the E-mobility landscape.

4.3.5. Data Security Policy

The Data Security Policy (DSP) acts as a shield, securing the confidentiality, integrity, and availability of data by outlining a multi-layered approach within the E-mobility ecosystem. The initial line of defence relies on technical safeguards, utilising measures such as data encryption (e.g., the robust AES-256 standard) to complicate information and deploy access controls such as firewalls and intrusion detection systems to serve as effective gatekeepers. Moreover, secure data storage practices further enhance protection and establish a clear response plan for data breaches, outlining steps to identify and contain the incident, notify affected users and regulators, and implement corrective actions to prevent future occurrences. Additionally, the DSP emphasises ongoing vigilance through incident management processes that define procedures for reporting, investigating, and remediating security incidents like unauthorised access attempts or malware infections. It underscores the importance of security awareness training for all stakeholders within the E-mobility ecosystem, empowering them to identify and mitigate potential threats.

4.3.6. Data Integrity Policy

The Data Integrity Policy (DIP) in E-mobility is a cornerstone for maintaining the accuracy, completeness, and consistency of data throughout its lifecycle. This policy outlines procedures to validate data accuracy, employing checks and cleansing techniques during collection and processing. Emphasising data lineage tracking, the DIP transparently documents the origin and transformation of data, ensuring traceability and identifying potential inconsistencies. With clear change management procedures, the DIP documents authorised data changes, employing version control for tracking different data versions. The policy also addresses error handling, correction procedures, and advocates regular monitoring and auditing to uphold data integrity. The benefits of a robust DIP in E-mobility encompass improved decision-making, enhanced operational efficiency, increased user trust, and regulatory compliance. For instance, the DIP may prescribe validation rules for charging station data and establish data lineage for electric vehicle

Funded by the European Union

trip data, ensuring accuracy and reliability. By adhering to a comprehensive Data Integrity Policy, stakeholders in the E-mobility sector can confidently navigate reliable data, fostering trust, efficiency, and informed decision-making for a sustainable E-mobility future.

These dimensions serve as a foundation for applying data governance policies to various stakeholders and their corresponding data types (Discussed in Table 10), as presented in Table 11.

Table 11. Data governance policies for the different stakeholder's data types (Table 10) in the E-mobility

Stakeholders	Data Governance Policy
Power Grid (TSO & DSO) Data	• **ACP:** Restricted access for authorised personnel (engineers, system operators) based on role and need-to-know principle. DSO may have stricter access for low-voltage grid data compared to TSO for high-voltage data. • **DUP:** Data used for grid planning, monitoring, and operation. Sharing anonymised data with E-mobility operators for grid impact assessment. • **DRP:** Long-term retention for grid planning purposes. Outage data retention based on regulatory requirements. • **DPP:** Not applicable (no personal data). • **DSP:** High security measures (encryption, access controls) to protect critical infrastructure data. Regular security audits and vulnerability assessments. • **DIP:** Data validation checks to ensure accuracy of grid data (e.g., sensor calibration). Automated anomaly detection for potential errors.
Utility Company Data	• **ACP:** Access limited to authorised personnel for billing, customer service, and regulatory reporting. E-mobility operators granted access to anonymized charging data with user consent. • **DUP:** Data used for billing, customer service, and grid management. Sharing anonymized data with E-mobility operators for service improvement. • **DRP**: Billing data retention based on tax regulations. Metering data retention based on regulatory requirements. Aggregated charging data retention based on business needs. • **DPP:** Anonymized data protects user privacy. User consent required for non-anonymized data usage (e.g., personalised marketing). • **DSP:** Secure data storage and access controls. Regular data backups and disaster recovery plan. • **DIP:** Data validation checks for metre readings and billing data. Reconciliation of energy consumption data.
Energy Aggregator Data	• **ACP:** Access restricted to authorised personnel for data analysis and trading purposes. Potential access for E-mobility operators with partnership agreements. • **DUP:** Data used for energy trading, portfolio optimization, and

Funded by the European Union

	market analysis. Sharing anonymized data with E-mobility operators for grid impact assessment (optional). ● **DRP**: Retention period based on business needs and regulatory requirements. ● **DPP:** Not applicable (no personal data). ● **DSP:** Secure data storage and access controls. Data anonymization techniques to protect source information. ● **DIP:** Data quality checks for consistency and accuracy. Verification of data sources (e.g., power plants, renewable energy generators).
Charging Station Data	● **ACP:** Limited public access to location data and availability. Station operator has full access for management purposes. E-mobility operators may have access with partnership agreements. ● **DUP:** Data used for station operation, maintenance, and user information (availability). Sharing anonymized energy dispensed data with E-mobility operators. ● **DRP**: Location data and real-time availability may have shorter retention periods. Energy dispensed data retention based on business needs and regulatory requirements (e.g., tax purposes). ● **DPP:** Not applicable (no personal data). ● **DSP:** Secure data storage and access controls. Regular system checks to ensure data accuracy and station functionality. ● **DIP:** Validate power rating, connector types, real-time availability, and energy dispensed data. Ensure consistent data formats.
Charging Station Operator	● **ACP:** Access restricted to authorised personnel for station management and customer service. Potential access for E-mobility operators with partnership agreements. ● **DUP:** Data used for station network management, maintenance planning, and customer service. Sharing anonymized usage statistics with E-mobility operators for grid impact assessment. ● **DRP**: Location data and real-time availability may have shorter retention periods. Energy dispensed data retention based on business needs and regulatory requirements (e.g., tax purposes). Maintenance data retention based on warranty periods and equipment lifespan. ● **DPP:** User consent required for collecting and using personal data (e.g., contact information). ● **DSP:** Secure data storage and access controls. Regular data backups and disaster recovery plan. ● **DIP:** Ensures accurate station info (power rating, availability), reliable energy measurement, and consistent data formats for efficient management and user trust.
E-Mobility Operator	● **ACP:** Restrict access to authorised personnel for data analysis, service planning, and network management. Grant limited access to E-mobility service providers with partnership agreements for data exchange (e.g., trip planning data for charging network optimization). ● **DUP:** Use data to improve service offerings (e.g., optimise station

Funded by the European Union

	locations, predict energy demand). Develop data-driven insights for grid impact assessment and collaborate with TSO/DSO for grid management. Anonymize data before sharing with third-party service providers (e.g., for market research). ● **DRP**: Retain raw trip data for a short period (e.g., weeks or months) for service improvement purposes. Longer retention (years) for anonymized and aggregated data for trend analysis and business planning. Comply with regulatory requirements for data retention. ● **DPP:** Clearly communicate data collection practices to users and obtain explicit consent for collecting personal data (e.g., location data for trip planning). Provide users with access to their data and allow them to request data correction or deletion. Anonymize data before using it for purposes beyond service delivery (e.g., marketing). ● **DSP:** Implement robust security measures to protect user data (e.g., encryption, access controls). Regularly monitor and update security protocols to address evolving threats. Conduct security audits and vulnerability assessments to identify and mitigate risks. ● **DIP:** E-mobility operators rely on data from charging stations (provided by charging station operators) and ensure its quality through data validation techniques.
Electric Vehicle	● **ACP:** Access to data is primarily restricted to the Electric Vehicle user. Limited access granted to authorised personnel from the EV manufacturer with user consent for diagnostics and software updates. ● **DUP:** User determines data usage purposes (e.g., trip monitoring, charging history). EV manufacturers use anonymized data for vehicle performance analysis and improvement. ● **DRP**: User determines data retention period for their trip and charging information. EV manufacturers may retain anonymized data for longer periods for research and development purposes (based on user consent). ● **DPP:** EV user has complete control over data collection and sharing preferences. EV manufacturers clearly explain data usage practices and obtain user consent before collecting personal data. Users have the right to access, rectify, or erase their data. ● **DSP:** EV manufacturers implement security measures to protect user data stored in the vehicle (e.g., in-vehicle infotainment system). Secure communication protocols for data transmission between EV and external systems. ● **DIP:** EVs rely on data from charging stations, and the DIP implemented by charging station operators ensures data accuracy.
Electric Vehicle User	● **ACP:** Electric Vehicle users have full control over access to their data stored in the car and mobile applications. ● **DUP:** User determines how their data is used (e.g., sharing trip data with friends, allowing manufacturers to collect anonymized data). ● **DRP**: User decides how long their data is stored on the EV and

Funded by the European Union

	mobile apps. ● **DPP:** Users have the right to access, rectify, or erase their data. E-mobility service providers must clearly explain data collection practices and obtain user consent before collecting any personal data. ● **DSP:** Users are responsible for choosing strong passwords and practising safe app download habits to protect their data on mobile devices used for EV charging and trip management. ● **DIP:** Users indirectly benefit from the DIP implemented by charging station operators, ensuring accurate information about station availability and functionality.

4.4. Semantic-Web Ontology based Data Space and Governance for E-Mobility

This section is dedicated to the strategic development of a semantic-web-based ontology tailored specifically for the data space and data governance in the E-mobility sector. The primary objective is to define the architectural components, identify and define the ontology's purpose, scope, classes, objects, and data properties, ensuring a comprehensive and technically precise representation. In essence, this initiative seeks to create a structured framework that encapsulates the intricate relationships and dependencies within the E-mobility domain. The ontology will not only facilitate seamless data exchange but will also provide a standardised and interoperable foundation for classifying and organising information. This entails a thorough exploration of the various entities, their attributes, and their interconnections, aligning with the E-mobility sector.

4.4.1. Architecture of the Semantic-Web Ontology for E-Mobility Data Space and Governance

Following the advantages outlined in the requirement analysis section for the hybrid data governance framework, this work aims to develop a hybrid architecture. In this architecture, data governance responsibilities are distributed between data owners, who interact with the ontology to define their data governance, and FLOW data managers, who are responsible for centrally managing metadata, ontology, and mapping functionalities. The proposed architecture, illustrated in Figure 13, highlights the interaction of entities in E-mobility, with their functions discussed in the following.

Funded by the European Union

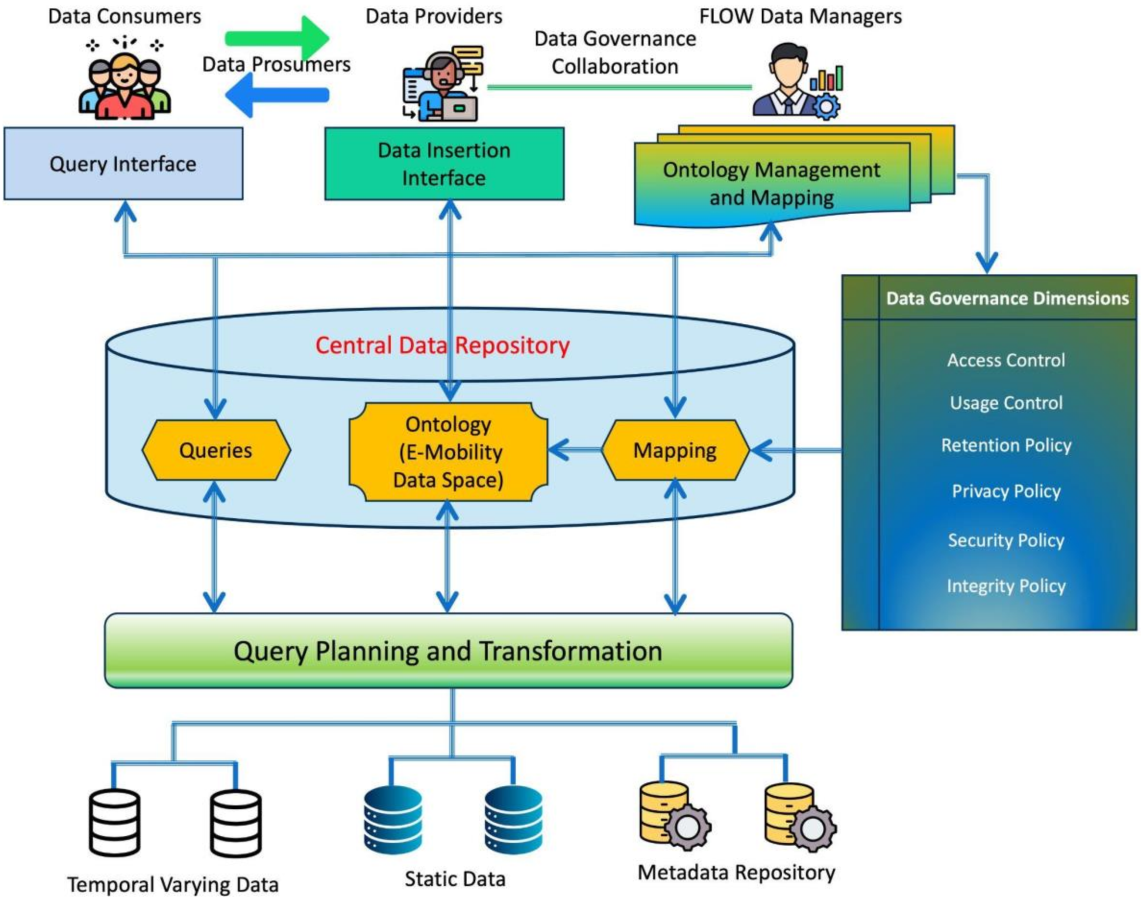

Figure 13. FLOW reference architecture for data space and data governance in the E-mobility Sector, highlighting various functional entities interacting with ontology for data provision, utilisation, and management.

- **Data Consumers:** Entities in the E-mobility sector that interact with the data space ontology through the query interface to utilise data for their operations. Several data consumers in the E-mobility sector are identified and presented in Table 10.
- **Data Providers:** These are entities within the E-mobility sector that serve as sources of data, supplying information to the data space ontology. Data providers play a crucial role in contributing relevant data that can be accessed and utilised by data consumers for various operations. The specific data providers identified in Table 10 are presented as key contributors to the data ecosystem in the E-mobility sector. The primary responsibility of data providers is to supply data and collaborate with the FLOW data manager to discuss and implement various data governance policies that must be fulfilled when utilising their data.
- **Data Prosumers:** In Table 10, the interchange between data providers and consumers illustrates that an entity can function as both a data provider and a data consumer, transforming it into a data "prosumer" entity. This role-switching is accentuated with double arrows and labelled as data prosumers in Figure 12.

Funded by the European Union

- **FLOW Data Manager:** The FLOW data managers constitute the IT expert team responsible for ontology management and mapping data governance policies, collaborating closely with data providers. They maintain metadata and facilitate the implementation of data policies defined by data owners, providing comprehensive management services to support consumers, producers, and prosumers.
- **Data Governance Dimensions:** The term "data governance dimensions" refers to various governance policies essential for effective data utilisation. These dimensions have been detailed in subsection 4.3 and are systematically mapped to the specific requirements of the E-mobility sector in Table 11.
- **Data Space Ontology:** The ontology serves as the cornerstone of the E-mobility data space and acts as a shared vocabulary, formally defining the entities, their properties, and the relationships between them. This structured knowledge base enables several key functionalities:
    - *Data Type Management:* The ontology acts as a schema, defining the data types (e.g., integer, geo-location) associated with each property. This facilitates consistent data representation and exchange across the ecosystem.
    - *Query Planning and Transformation:* By understanding the relationships between entities and properties, the ontology empowers the query planning module. It can translate user queries (data owners and consumers) into machine-understandable formats suitable for retrieving relevant information from diverse data sources.
    - *Data Policy Enforcement:* The ontology can be linked to specific data governance policies (e.g., AccessControlPolicy, DataPrivacyPolicy) through annotations. This allows data managers to define access control rules and data usage constraints directly within the ontology. When a user (data owner) interacts with the system, the query planning module can verify compliance with these policies before data access or manipulation is granted.
- **Data:** Data constitutes an asset within the E-mobility data space, demanding maintenance, and protection in compliance with regulations. In the realm of E-mobility, there are three distinct data types: metadata, serving as the centralised data dictionary managed by the FLOW IT expert team; static data, representing information that remains constant over time (e.g., EV user registration data); and temporal varying data, such as the state-of-charge of the EV battery, which undergoes frequent changes. Static and temporal data are provided by data owners and utilised by data consumers.

4.4.2. Purpose of E-Mobility Ontology

The E-mobility ontology aims to provide a standardised and shared vocabulary for representing knowledge within the E-mobility domain, specifically focusing on data spaces and data governance. This ontology will facilitate:

Funded by the European Union

- **Seamless Data Exchange:** By establishing a common understanding of concepts, entities, and relationships, the ontology enables smooth data exchange between different stakeholders in the E-mobility ecosystem (e.g., power grid, utility companies, energy aggregators, E-mobility service providers, charging station operators, electric vehicles, and electric vehicle users).
- **Interoperable Data Management:** The ontology allows for consistent data representation across various E-mobility data spaces, promoting interoperability and simplifying data integration for the stakeholders within the E-mobility data landscape.
- **Enhanced Data Governance:** The ontology can be used to define rules and policies for data access, ownership, and usage within the data space framework, supporting secure and trusted collaboration and data governance framework among the participants.
- **Improved Reasoning and Decision-Making:** By enabling machines to understand the meaning of E-mobility data, the ontology can support automated reasoning and informed decision-making within the data space environment.

4.4.3. Scope of the E-Mobility Ontology

This ontology is not intended to be an exhaustive representation of the entire E-mobility and mobility domains. Instead, it focuses on the core concepts critical for effective data management and governance within data spaces for E-mobility applications. The key concepts focused on in the E-mobility domain relevant to data spaces and data governance include the following.

- **E-Mobility Entities:** Vehicles (cars, buses, scooters, etc.), charging stations, power grid, utility companies, E-mobility service providers, energy aggregators, electric vehicles, and electric vehicle user's entities within the E-mobility ecosystem.
- **Data Representation:** Standardised definitions for data points related to vehicles (battery level, range), charging sessions (duration, energy consumption), and trips (distance travelled, location data), charging cost, charging load, demand response management, incentives, energy optimization.
- **Data Space Roles and Processes:** Roles like data provider, data consumer, and data administrator within the data space. It will also encompass data access control mechanisms and data governance processes.
- **Location and Geospatial Information:** Representation of geographical locations relevant to E-mobility, such as charging station locations and user locations.

4.4.4. Competency Questions

The competency questions further clarify the role of the ontology by guiding the development of the E-mobility ontology, ensuring it addresses key information needs within the context of data space and data governance. The FLOW E-mobility data space and governance ontology are expected to answer the following competency questions.

Funded by the European Union

- **Data Entities and Relationships:**
    - What Stakeholders are involved in a specific data exchange within the data space (e.g., Who provides charging data to an E-mobilityOperator)?
    - What Data Policies govern the data practices of a particular Stakeholder (e.g., What access control policies are applied by a Charging Station Operator)?
    - What type of Data does an Electric Vehicle own (e.g., What data is generated by an electric vehicle during a trip)?
- **Data Governance and Access Control:**
    - Who regulates the Power Grid used for charging electric vehicles (e.g., Which TSO or DSO is responsible for a specific region)?
    - Which Stakeholders can access real-time availability data of a Charging Station (e.g., Who has public access to charging station availability)?
    - Based on the access control policies, can a Utility Company access trip data from a Charging Station Operator (e.g., Does the Utility Company have the necessary permissions to use trip data)?
- **Data Usage and Analysis:**
    - What is the intended usage purpose of a specific data element (e.g., How is "billing Data" used by the Utility Company)?
    - Based on historical data and retention periods, can the ontology identify data that can be deleted (e.g., Is any "billing Data" older than 10 years)?
    - By analysing trip data, can the ontology identify areas with high demand for charging stations (e.g., Where would additional charging infrastructure be most beneficial)?
- **Additional Considerations:**
    - How can the ontology be used to verify compliance with specific Data Privacy Policy regulations?
    - Can the ontology be extended to accommodate new data types generated by future E-mobility technologies?
    - How can the ontology be used to identify potential security vulnerabilities based on the implemented security Measures for different data elements?

4.4.5. Development of the E-Mobility Data Space and Governance Ontology

For the development of the E-mobility data space and data governance ontology, we utilise the open-source Protégé software tool [57]. Protégé is an editor and framework developed by Stanford University for building intelligent systems, as shown in Figure 14. Supported by a robust

Funded by the European Union

community of academic researchers, governments, and corporate users, Protégé facilitates the creation of knowledge-based solutions across diverse research areas, including medicine, energy, transport, e-commerce, and organisational modelling. In this section, we identify various classes, object properties, data properties, and individuals to develop the E-mobility data space and data governance semantic web-based solution.

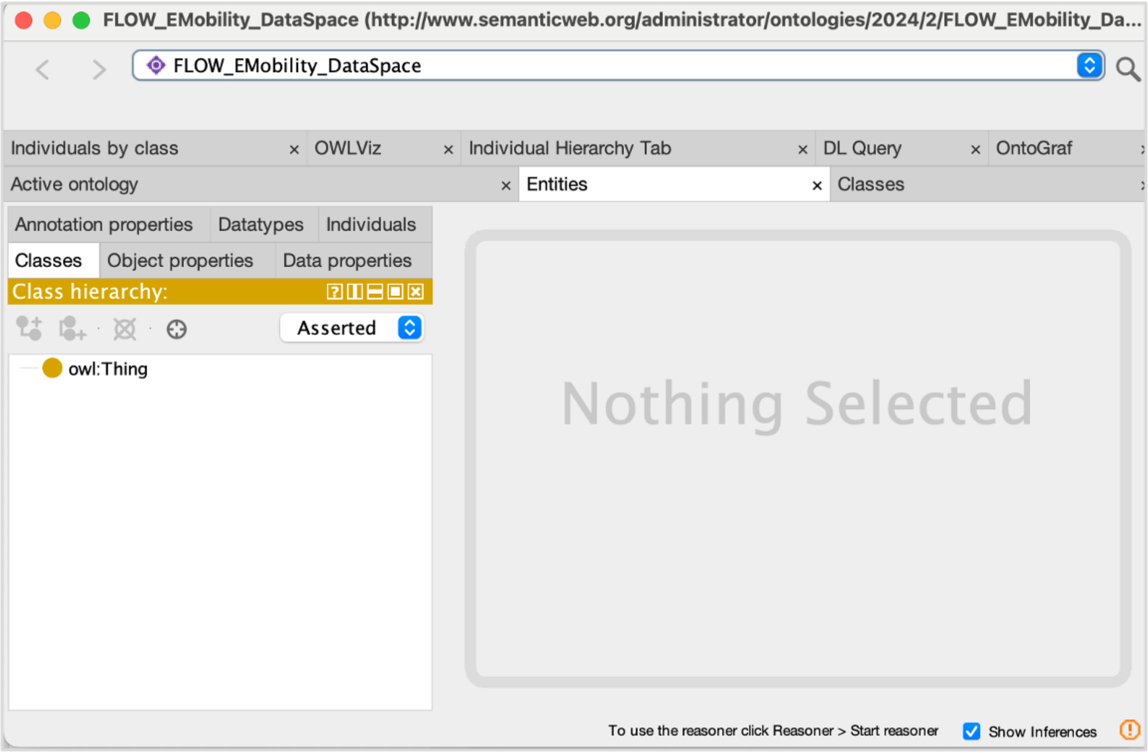

Figure 14. A representation of the Protege editor for implementing the FLOW E-Mobility data space and governance framework.

4.4.5.1. Classes in E-Mobility Data Space and Governance

Given that there are several entities involved in the E-Mobility landscape with hierarchical relationships, the following parent and child classes are identified for implementing the FLOW E-Mobility data space and governance framework, and are implemented in Protege, as shown in Figure 15.

- **Parent Classes:**
  - *Stakeholder (abstract):* Represents any entity involved in the E-mobility ecosystem.
  - *DataPolicy (abstract):* Represents different data governance policies.
  - *Data:* Represents any piece of information collected within the E-mobility ecosystem.
- **Child Classes:**

Funded by the European Union

- *InfrastructureProvider (inherits from Stakeholder):* Entities responsible for physical infrastructure.
    - *PowerGrid (inherits from InfrastructureProvider):* The electrical grid infrastructure.
    - *ChargingStation (inherits from InfrastructureProvider):* A location for electric vehicle charging.
- *GridOperator (inherits from Stakeholder):* Entities managing the electricity grid.
    - TransmissionSystemOperator (TSO) (inherits from GridOperator): Manages the high-voltage transmission grid.
    - *DistributionSystemOperator (DSO) (inherits from GridOperator):* Manages the low-voltage distribution grid.
- *EnergyProvider (inherits from Stakeholder)***:** Entities involved in energy generation and supply.
    - *UtilityCompany (inherits from EnergyProvider):* Sells electricity to consumers.
    - *EnergyAggregator (inherits from EnergyProvider):* Aggregates and manages energy resources.
    - FleetOperator (inherits from EnergyProvider): Energy aggregator that manages energy resources.
- *EMobilityService (inherits from Stakeholder):* Entities providing E-mobility related services.
    - *ChargingStationOperator (inherits from EMobilityService):* Operates charging stations and related services.
    - *EMobilityOperator (inherits from EMobilityService):* Provides services related to electric vehicles and charging.
    - BatterySwapingOperator (inherits from EnergyProvider): Provide battery swapping services.
- *Participant (inherits from Stakeholder):* Entities directly involved in using electric vehicles.
    - *ElectricVehicle (inherits from Participant):* A battery-powered electric vehicle.
    - *ElectricVehicleUser (inherits from Participant):* An individual using an electric vehicle.
- *AccessControlPolicy (inherits from DataPolicy):* Defines who can access specific data.
- *DataUsagePolicy (inherits from DataPolicy):* Specifies how data can be used.

Funded by the European Union

- *DataRetentionPolicyPolicy (inherits from DataPolicy):* Determines how long data is retained.
- *DataPrivacyPolicy (inherits from DataPolicy):* Outlines how personal data is protected.
- *DataSecurityPolicy (inherits from DataPolicy):* Defines security measures to protect data.
- *DataIntegrityPolicy (inherits from DataPolicy):* Ensures the accuracy and completeness of data.
- *InfrastructureData (inherits from Data):* Data related to E-mobility infrastructure (e.g., power grid data, charging station status).
- *VehicleData (inherits from Data):* Data generated by electric vehicles (e.g., battery level, trip information).
- *UserData (inherits from Data):* Personal data associated with electric vehicle users.
- *Billing Data (inherits from Data):* Energy billing data of electric vehicles.
- *Energy Data (inherits from Data):* Energy consumption data.

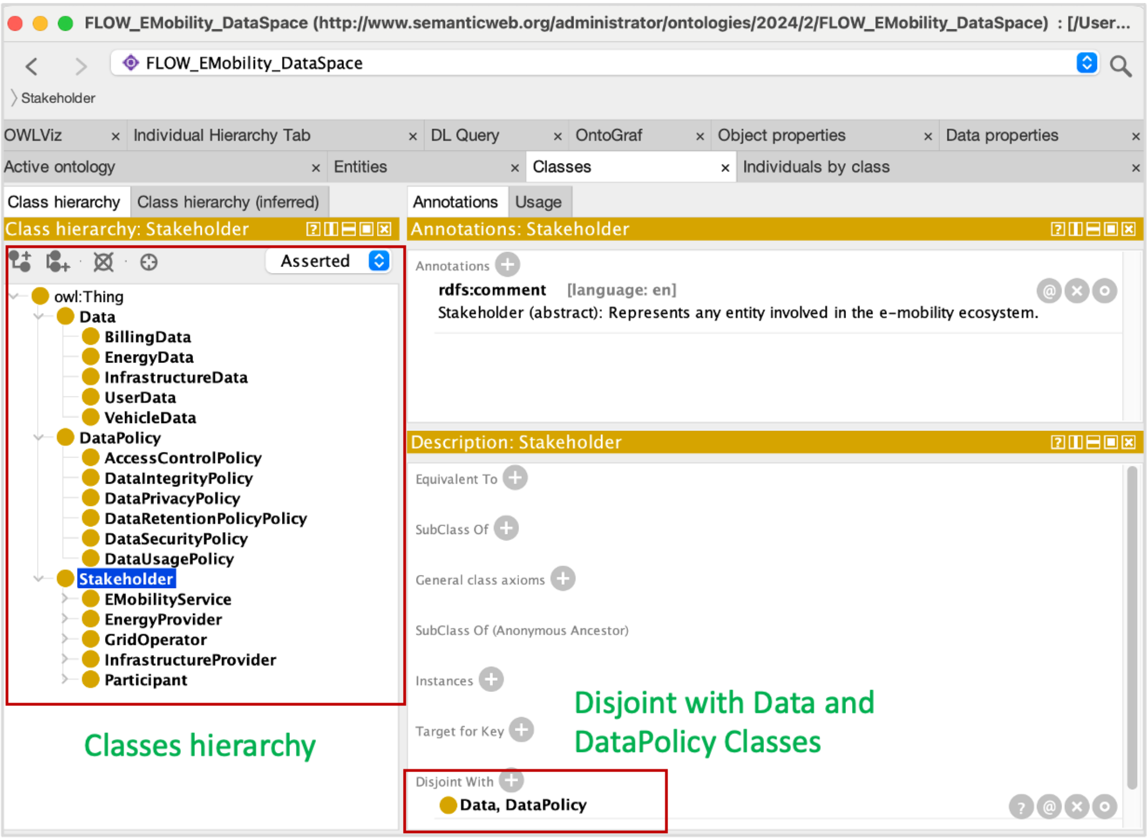

Figure 15. Class hierarchy of FLOW E-Mobility data space and governance framework.

Funded by the European Union

4.4.5.2. Object Properties

Object properties serve as the binding elements that connect entities within an ontology, functioning akin to verbs by delineating the relationships between instances of classes. In the FLOW E-Mobility Data Space and Governance ontology, the following object properties for the parent and child classes have been identified and implemented in Protégé, as shown in Figure 16.

- **hasPolicy (Stakeholder, DataPolicy):** Links a Stakeholder to the DataPolicy documents governing their data practices.
- **regulates (GridOperator, PowerGrid):** Connects a TSO or DSO to the PowerGrid they manage.
- **owns (Stakeholder, Data):** Relates an entity to the data it possesses.
- **providesAccessTo (Stakeholder, Stakeholder):** Connects a data provider to the stakeholder it grants access to the data.
- **usesDataFrom (Stakeholder, Stakeholder):** Links a data user to the stakeholder providing the data.
- **isConnectedTo (ChargingStation, PowerGrid):** Connects a ChargingStation to the PowerGrid it receives electricity from.
- **operates (ChargingStationOperator, ChargingStation):** Relates a ChargingStationOperator to the ChargingStations they manage.
- **uses (ElectricVehicleUser, ElectricVehicle):** Links an ElectricVehicleUser to the ElectricVehicle they are using.
- **governsData (DataPolicy, Data):** Connects a DataPolicy to the specific Data it applies to.
- **isOwnedBy (Data, Stakeholder):** Identifies the owner of a specific piece of Data.
- **isConsumedBy (Data, Stakeholder):** Links Data to the Stakeholder consuming it.
- **isManagedBy (Data, Stakeholder):** Identifies the Stakeholder responsible for managing specific Data.

Funded by the European Union

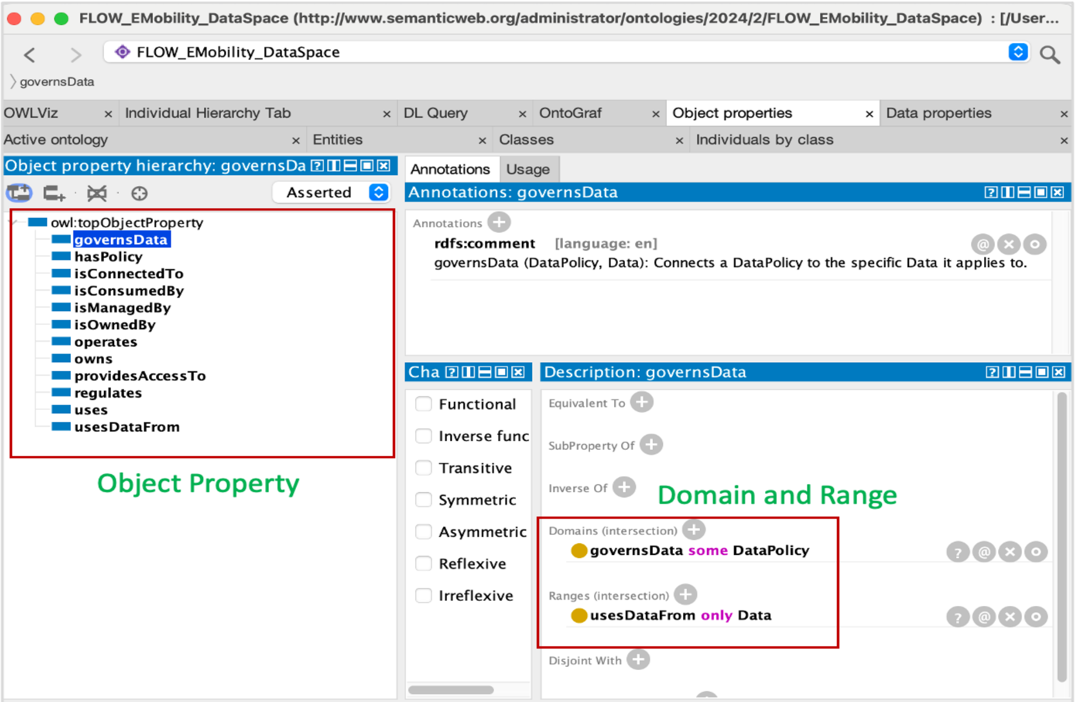

Figure 16. Object properties of FLOW E-Mobility data space and governance framework.

4.4.5.3. Data Properties

Data properties play a crucial role in ontology, serving as the descriptive sidekicks to object properties. While object properties establish relationships between entities, like verbs, data properties function as adjectives, offering specific details about the individual characteristics of entities within the ontology. These properties contribute to an understanding of the attributes and features associated with instances of classes, enriching the overall representation of knowledge in each domain. Thus, the data properties provide a means to capture and express the inherent qualities, measurements, or values associated with entities, thereby enhancing the granularity and specificity of the represented information. In the FLOW E-mobility data space ontology, the following data properties are identified and implemented in the protege, as shown in Figure 17.

- **dataType (string):** This property specifies the fundamental data type of the information, such as text (string), number (integer), or geographic location (geo-location).
- **description (string):** This property provides a human-readable explanation of the data element, clarifying its purpose and meaning within the context of the ontology.
- **location (geo-location):** This property defines the geographic coordinates (latitude and longitude) of a ChargingStation, enabling spatial analysis and visualisation.
- **powerRating (float):** This property indicates the maximum power output capacity of a ChargingStation, measured in units like kilowatts (kW).
- **batteryCapacity (integer):** This property specifies the total energy storage capacity of an ElectricVehicle battery, typically measured in kilowatt-hours (kWh).

Funded by the European Union

- **currentCharge (integer):** This property represents the remaining energy level of an ElectricVehicle battery, often expressed as a percentage or a value relative to the total capacity.
- **retentionPeriod (integer):** This property defines the duration for which a specific data element is stored under the regulations of a DataRetentionPolicyPolicy. It can be specified in days, months, or years.
- **securityMeasures (string):** This property lists the security protocols implemented within a DataSecurityPolicy to protect data from unauthorised access or modification (e.g., encryption, access control mechanisms).
- **validationMethods (string):** This property describes the techniques used by a DataIntegrityPolicy to verify the accuracy and completeness of data. Examples include checksums for data integrity verification or data provenance tracking to ensure data origin.
- **billingPeriod (string):** This property specifies the time frame covered by a billing record within BillingData, such as a month or quarter.
- **energyConsumption (integer):** This property represents the total amount of energy consumed during a specific billing period (BillingData) or captured at a specific time (EnergyData). It can be measured in kilowatt-hours (kWh) or similar units.
- **cost (float):** This property indicates the total financial cost associated with energy consumption reflected in BillingData. The data type is a floating-point number to accommodate variable costs.
- **timestamp (date-time):** This property captures the exact date and time when a specific piece of EnergyData was collected, allowing for time-series analysis of energy usage patterns.
- **stakeholderID (string):** This unique identifier helps distinguish individual Stakeholder entities within the ontology.
- **voltageLevel (string):** This property specifies the voltage level of a PowerGrid (e.g., high-voltage, medium-voltage, low-voltage), relevant for power transmission and distribution.
- **areaOfResponsibility (geo-location-string):** This property defines the geographic region managed by a specific GridOperator, enabling visualisation of their coverage area.
- **energyMix (string):** This property describes the various energy sources used by an EnergyProvider to generate electricity (e.g., renewable sources like solar or wind, non-renewable sources like fossil fuels).
- **serviceArea (geo-location-sting):** This property defines the geographic region covered by the services offered by an EMobilityService.
- **userID (string):** This unique identifier helps distinguish individual ElectricVehicleUser entities within the ontology.

Funded by
the European Union

- **authorizedRoles (string):** Within an AccessControlPolicy, this property specifies the roles (e.g., administrator, user) authorised to access specific data.
- **anonymizationMethods (string):** This property describes the techniques used within a DataUsagePolicy to anonymize data if applicable, protecting personal information.
- **personalDataCategories (string):** This property identifies the categories of personal data collected within UserData, such as name, location information, or usage data, for transparency and compliance with data privacy regulations.

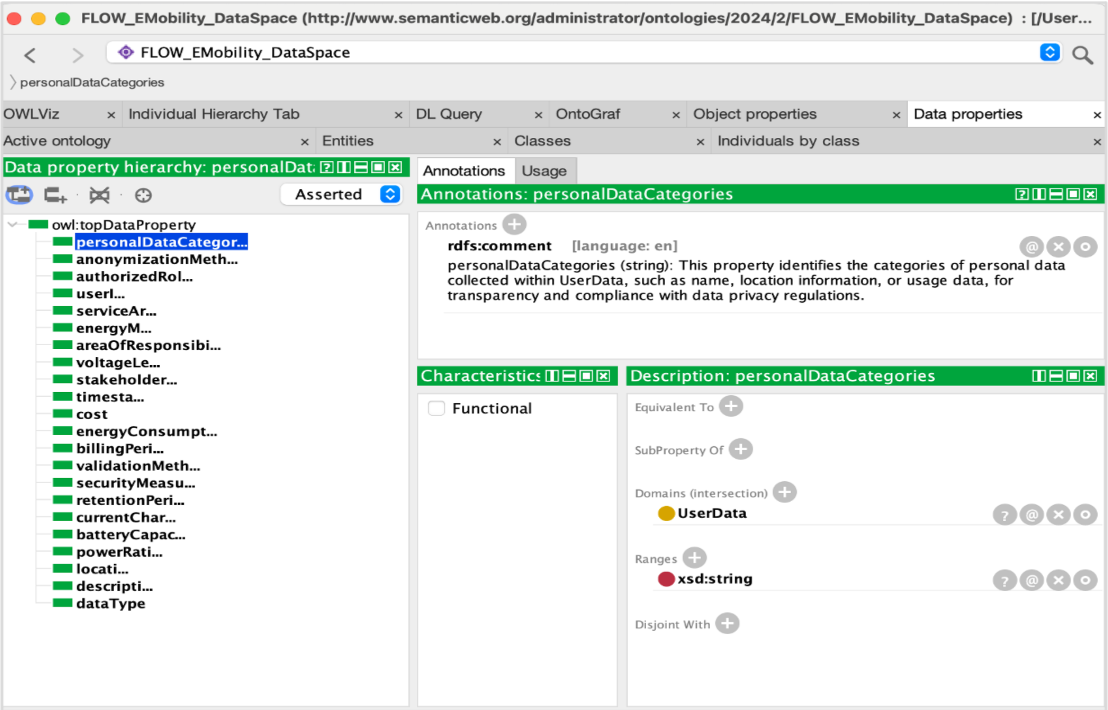

Figure 17. Data properties of FLOW E-Mobility data space and governance framework.

4.4.5.4. Validation and Visualization

To validate the FLOW E-mobility data space and governance ontology, we employed the HermiT 1.4.3.456 reasoner and description logic (DL) query module. To execute the DL query, we populated the ontology with the following sample dataset. The query results for the stakeholders and DataPolicy classes are depicted in Figure 18, while the comprehensive overview of the entire ontology is provided in Figures 19.

- **Stakeholder:** Tesla Inc. (ElectricVehicle Manufacturer)
- **Stakeholder:** National Grid (GridOperator - TSO)
- **Stakeholder:** EverSource Energy (EnergyProvider - Utility Company)
- **Stakeholder:** ChargePoint (EMobilityService - Charging Station Operator)
- **Stakeholder:** Electrify America (EMobilityService - Charging Station Operator)
- **Stakeholder:** City of Los Angeles (Participant - Owns ElectricVehicle Fleet)

Funded by
the European Union

- **Stakeholder:** John Doe (Participant - ElectricVehicleUser)
- **Stakeholder:** Acme Delivery Services (Participant - FleetOperator)
- **DataPolicy:** Tesla Data Privacy Policy (governs UserData collected by Tesla vehicles)
- **DataPolicy:** National Grid Data Security Policy (defines security measures for PowerGrid data)
- **DataPolicy:** EverSource Energy Data Retention Policy (specifies how long billing data is retained)
- **DataPolicy:** ChargePoint Access Control Policy (defines who can access charging station usage data)
- **Data:** Tesla Model S Vehicle Data (contains information about battery level, trip information)
- **Data:** National Grid Power Grid Status Data (includes real-time data on power generation and distribution)
- **Data:** EverSource Energy Billing Data for John Doe (contains energy consumption and cost details)
- **Data:** ChargePoint Station Usage Data (tracks charging sessions at a specific station)
- **ElectricVehicle:** John Doe's Tesla Model 3 (currentCharge: 70%, batteryCapacity: 75 kWh)
- **ElectricVehicle:** Acme Delivery Van #123 (assigned to John Smith, currentCharge: 25%, batteryCapacity: 50 kWh)

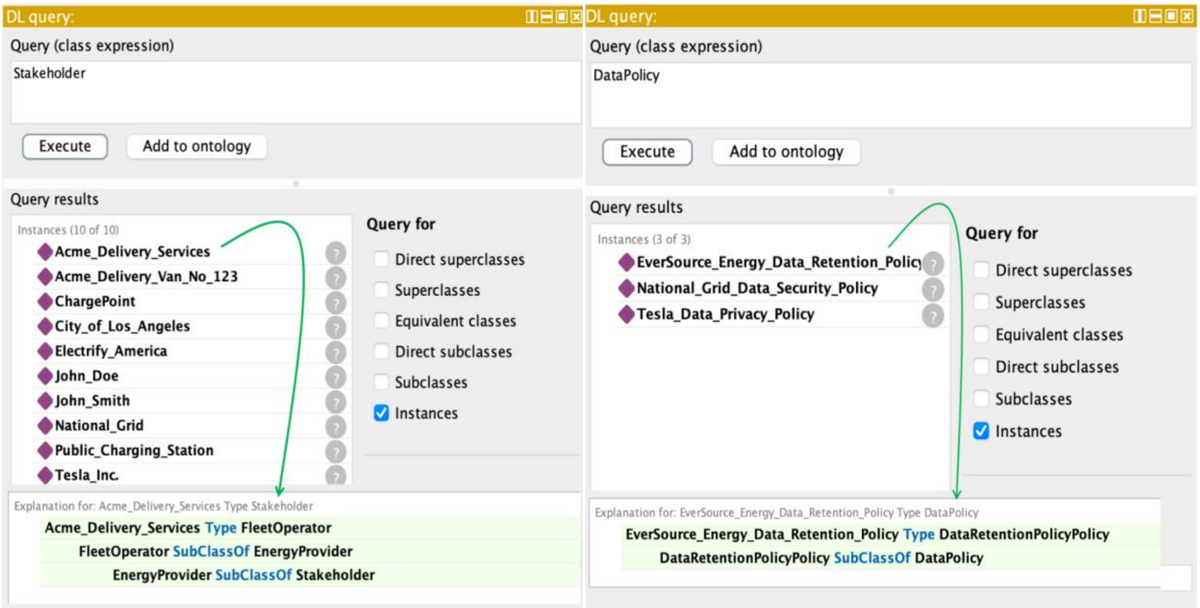

Figure 18. The DL query output of FLOW E-mobility ontology for the instances of the Stakeholder and DataPolicy classes.

Funded by the European Union

Figure 19. A representation of the parent and child class hierarchy for the FLOW E-mobility data space and governance ontology.

Funded by the European Union

5. Conclusion

5.1. Contribution

This report presented the importance of data governance in transitioning energy systems from centralized generation to distributed renewable energy generation and tailored to the development of an E-mobility data governance framework. This development is based on the emerging stakeholders, their interactions, and dependencies on each other's data, which have arisen from the power system transition, as well as the EU policies concerning the necessity for data space and data governance in alignment with EU initiatives.

Subsequently, a detailed requirement analysis is conducted which focused on the design principles and exploration of various types of the data governance frameworks. These frameworks are then compared following the ISO/IEC 38505-1 accountability map for data governance, to aid in selecting specific frameworks tailored to the needs of energy sector organizations. The report further delves into various data spaces and governance within EU projects, particularly focusing on the energy sector.

Eventually, the report developed a semantic web-based data governance framework for E-mobility. Initially, a detailed architecture is devised to identify key data governance dimensions, stakeholders, and their corresponding data generation, consumption, and interactions. All stakeholders, data, and identified governance dimensions are characterized using classes, objects, and properties. These are then utilized in the Protégé tool and tested through descriptive language (DL) queries with sample data.

5.2. Limitations

While this document sheds light on various aspects of the energy system and emerging stakeholders, along with the development of a semantic web-based data governance framework, it is important to note that incorporating the various emerging stakeholders and their data governance poses challenges. Obtaining the entire dataset of all stakeholders is one of the main challenges, and therefore, this framework is tested with sample data.

5.3. Future Possible Direction

The work aims to collect and develop a detailed dataset for testing the performance of the developed framework and providing an open dataset for further research and development of data governance frameworks.

Moreover, given that the framework prioritizes data governance over data space, integrating the developed framework with other E-mobility data spaces through APIs will likely enhance the performance of these spaces. Therefore, conducting a feasibility study to assess the applicability of integrating the developed governance framework with the existing EU ontology (Int:net and BRIDGE etc.) developed for the data space is a promising future direction.

Funded by the European Union

References

[1]. Kabeyi, Moses Jeremiah Barasa, and Oludolapo Akanni Olanrewaju. "Relationship between electricity consumption and economic development." *2021 International Conference on Electrical, Computer and Energy Technologies (ICECET)*. IEEE, 2021.

[2]. Kabeyi, Moses Jeremiah Barasa, and Oludolapo Akanni Olanrewaju. "Biogas production and applications in the sustainable energy transition." *Journal of Energy* 2022 (2022): 1-43.

[3]. Ponce-Jara, M. A., et al. "Smart Grid: Assessment of the past and present in developed and developing countries." *Energy strategy reviews* 18 (2017): 38-52.

[4]. Saumen, D., S. Alok Kumar, and S. Pradip Kumar.2021. “Smart Grid Modernization: Opportunities and Challenges.”InElectric Grid Modernization, edited by G. Mahmoud, Ch. 2. Rijeka: IntechOpen

[5]. De, Arpita. "Optimal sizing and positioning of grid integrated distributed generator." Thesis, Maulana Azad National Institute of Technology Bhopal, India, 2020.

[6]. Energy Matching Project. "RES harvesting in the built Environment" URL: https://www.energymatching.eu/project/. Accessed 23 December 2023.

[7]. Nyangon, Joseph. "Smart energy frameworks for smart cities: The need for polycentrism." *Handbook of smart cities* (2020): 1-33.

[8]. Kirschen, Daniel S., and Goran Strbac. *Fundamentals of power system economics*. John Wiley & Sons, 2018.

[9]. McIlwaine, Neil, et al. "A state-of-the-art techno-economic review of distributed and embedded energy storage for energy systems." *Energy* 229 (2021): 120461.

[10]. Ahmad, Tanveer, and Dongdong Zhang. "Using the internet of things in smart energy systems and networks." *Sustainable Cities and Society* 68 (2021): 102783.

[11]. Noris, Federico, et al. "Demand response in blocks of buildings D2. 1: market and stakeholder analysis." (2016). Available at: https://research.tees.ac.uk/en/publications/demand-response-in-blocks-of-buildings-d21-market-and-stakeholder. Accessed on January 5, 2024.

[12]. Alvial-Palavicino, Carla, et al. "A methodology for community engagement in the introduction of renewable based smart microgrid." *Energy for sustainable development* 15.3 (2011): 314-323.

[13]. Doumen, Sjoerd C., Phuong Nguyen, and Koen Kok. "Challenges for large-scale Local Electricity Market implementation reviewed from the stakeholder perspective." *Renewable and Sustainable Energy Reviews* 165 (2022): 112569.

[14]. Teng, Sin Yong, et al. "Recent advances on industrial data-driven energy savings: Digital twins and infrastructures." *Renewable and Sustainable Energy Reviews* 135 (2021): 110208.

[15]. Radi, Mohammed, et al. "Energy Data Flow in Smart Grids-A Conceptual Model for Addressing Various Use Cases." (2019).

[16]. Newman, David, and Debra Logan. "Governance is an essential building block for enterprise information management." *Gartner Research, Stamford, CT* 4 (2006).

[17]. Mahanti, Rupa. "Data Governance Implementation: Critical Success Factors." *Software Quality Professional* 20.4 (2018).

Funded by the European Union

[18]. Plotkin, David. *Data stewardship: An actionable guide to effective data management and data governance*. Academic press, 2020.

[19]. Fetting, Constanze. "The European green deal." *ESDN report* 53 (2020).

[20]. Saleem, M. Usman, et al. "Integrating smart energy management system with internet of things and cloud computing for efficient demand side management in smart grids." *Energies* 16.12 (2023): 4835.

[21]. Drexl, Josef, et al. "Position Statement of the Max Planck Institute for Innovation and Competition of 25 May 2022 on the Commission's Proposal of 23 February 2022 for a Regulation on Harmonised Rules on Fair Access to and Use of Data (Data Act)." *Max Planck Institute for Innovation & Competition Research* Paper 22-12 (2022).

[22]. Hoofnagle, Chris Jay, Bart Van Der Sloot, and Frederik Zuiderveen Borgesius. "The European Union general data protection regulation: what it is and what it means." *Information & Communications Technology Law* 28.1 (2019): 65-98.

[23]. Bosco, F., Cazzaniga, A., & Hussein, S. (2023, December 29). Technological components to enable data-driven markets for electromobility. FLOW Deliverable 3.3.

[24]. Commission of the European Communities. "Digitalising the energy system - EU action plan." Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2022) 552 final, Strasbourg, 18 Oct. 2022.

[25]. Zgajewski, Tania. *Smart electricity grids: A very slow deployment in the EU*. Academia Press, 2015.

[26]. Plan, Action. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions." *European Commission* (2011).

[27]. Chowdhury, Shahriar Ahmed. "National Solar Energy Roadmap, 2021–2041." *Sustainable and Renewable Energy Authority SREDA, Dhaka* (2020).

[28]. European Commission, Directorate-General for Mobility and Transport, Sustainable Transport Forum – Best practices guide for permitting and grid connection procedures for recharging infrastructure, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2832/944637.

[29]. Zingales, Nicolo. "Data collaboratives, competition law and the governance of EU data spaces." *Research Handbook on the Law and Economics of Competition Enforcement*. Edward Elgar Publishing, 2022. 8-49.

[30]. Pretzsch, Sebastian, Holger Drees, and Lutz Rittershaus. "Mobility Data Space." *Designing Data Spaces* (2022): 343.

[31]. Masilela, Lucia. *Data and information security governance in the Departments of Energy, Science and Technology, and Environmental Affairs*. Diss. University of Johannesburg, 2019.

[32]. Zygmuntowski, Jan J., Laura Zoboli, and Paul Nemitz. "Embedding European values in data governance: A case for public data commons." *Internet Policy Review* 10.3 (2021): 1-29.

[33]. Ladley, John. *Data governance: How to design, deploy, and sustain an effective data governance program*. Academic Press, 2019.

[34]. Watson, Jim, and Patrick Devine-Wright. "Centralisation, decentralisation and the scales in between: what role might they play in the UK energy system." *The future of electricity demand: Customers, citizens and loads* 69 (2011): 280.

Funded by the European Union

[35]. Sovacool, Benjamin K., Chukwuka G. Monyei, and Paul Upham. "Making the internet globally sustainable: Technical and policy options for improved energy management, governance and community acceptance of Nordic datacenters." *Renewable and Sustainable Energy Reviews* 154 (2022): 111793.

[36]. Buchmann, Marius. "The need for competition between decentralised governance approaches for data exchange in smart electricity grids—Fiscal federalism vs. polycentric governance." *Journal of Economic Behavior & Organisation* 139 (2017): 106-117.

[37]. Osofsky, Hari M., and Hannah J. Wiseman. "Hybrid energy governance." *U. Ill. L. Rev.* (2014): 1.

[38]. Lee, Sung Une, Hye-young Paik, and Salil S. Kanhere. "Human-Sensing Platforms and Ethical Considerations Throughout Their Data Life-Cycles." *IEEE Internet of Things Magazine* 7.1 (2024): 66-7.

[39]. Lee, Sung Une, Liming Zhu, and Ross Jeffery. "Designing data governance in platform ecosystems." (2018).

[40]. Khatri, Vijay, and Carol V. Brown. "Designing data governance." *Communications of the ACM* 53.1 (2010): 148-152.

[41]. ISO/IEC TR 38505-2 Information technology — Governance of IT — Governance of data — Part 2: Implications of ISO/IEC 38505-1 for data management Technologies. First edition, 2018-06. International Electrotechnical Commission, https://webstore.iec.ch/preview/info_isoiectr38505-2%7Bed1.0%7Den.pdf.

[42]. International Data Spaces Association. *Reference Architecture Model, Version 3.0*. Publisher: International Data Spaces Association, Address: Anna-Louisa-Karsch-Str. 2, 10178 Berlin, Germany, Editor: Sebastian Steinbuss, Copyright: International Data Spaces Association, April 2019. *International Data Spaces Association*, 2019, https://internationaldataspaces.org/wp-content/uploads/IDS-Reference-Architecture-Model-3.0-2019.pdf. Accessed 4 March 2024.

[43]. EU Horizon-2020 funded project, INTERRFACE (TSO-DSO-Consumer Interface architecture to provide innovative grid services for an efficient power system) available at: http://interrface.eu/The-project.

[44]. INTERRFACE Consortium. "Deliverable 5.5 Single Flexibility Platform: Demonstration Description and Results." 2019-2022. FIN, ELEN, CYB, AST, ELEK, EMP, ED. Copyright INTERRFACE Consortium, available at http://interrface.eu/sites/default/files/publications/INTERRFACE_D5.5_vPUBLIC.pdf. Accessed 6 March 2023.

[45]. INTERRFACE Consortium. "Deliverable 9.14 Report on the Foundations for the Adoption of New Network Codes 2." 2019-2022. AGEN, ENTSO. Copyright INTERRFACE Consortium, available at http://interrface.eu/sites/default/files/publications/INTERRFACE_D9.14_v1.0.pdf. Accessed 6 March 2023.

[46]. Kukk, Kalle et al. "Recommended Data Exchange Conceptual Model for Europe." Deliverable 5.1. November 2021. EU-SYSFLEX, https://eu-sysflex.com/wp-content/uploads/2021/11/EU-SysFlex-D5.1-Data-exchange-model-v.1.pdf. Accessed 6 March 2024.

[47]. Siöstedt, Simon, and Mats Wang-Hansen, AFRY. "Market and Governance of Existing Data Access & Exchange Platforms." Deliverable 5.1.3, March 2021. EU-SYSFLEX, https://eu-sysflex.com/wp-content/uploads/2021/03/EUSYSFLEX-5.1.3-Report-Data-Platforms-FINAL-1.pdf. Accessed 6 March 2024.

[48]. Minh-Quan, Nguyen et al. "Report on Network Observability and Risk Assessment." Deliverable 3.1. Published on 31 October 2020. FlexiGrid, https://flexigrid.org/wp-content/uploads/2022/03/D-3.1-resubmitted-Report-on-network-observability-and-risk-assessment.pdf. Accessed 7 March 2024.

[49]. Digital Platform and Analytic Tools for Energy (Platoon). EU-Horizon 2020 Project, https://platoon-project.eu/about-platoon/overview/.

Funded by the European Union

[50]. SYNERGY. "SYNERGY EU-Horizon2020 project." https://synergyh2020.eu/about/#theproject. Accessed 8 March 2024.

[51]. UBI, et al. "Data Collection, Security, Storage, Governance & Management Services Bundles – Beta Release." Deliverable 3.2, 30 March 2021, https://smartinnovationnorway.com/synergy/wp-content/uploads/sites/19/2021/11/20210331_ubitech_SYNERGY_D3.2_Data_Collection_Storage_Governance__Management_Services_Bundles_Beta_Release_pu.pdf, accessed 8 March 2024.

[52]. OneNet. "OneNet EU-Horizon2020. Project". https://www.onenet-project.eu//project-brief/. Accessed 8 March 2024.

[53]. Kukk, K., Bosco, F., Lacerda, M., Sakas, V., Kapetanios, A., Kotsalos, K., et al. "Cross-stakeholder Data Governance for Energy Data Exchange." Deliverable 6.2, March 29, 2023. Accessed on March 9, 2024. https://www.onenet-project.eu//wp-content/uploads/2023/04/D6.2-OneNet-v1.0.pdf.

[54]. Venegas, Felipe Gonzalez, Marc Petit, and Yannick Perez. "Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services." *Renewable and Sustainable Energy Reviews* 145 (2021): 111060.

[55]. Bokolo, Anthony Jnr. "Examining the adoption of sustainable eMobility-sharing in smart communities: diffusion of innovation theory perspective." *Smart Cities* 6.4 (2023): 2057-2080.

[56]. Sabireen, H., S. Kirthica, and Rajeswari Sridhar. "Secure data archiving using enhanced data retention policies." *Data Science Analytics and Applications: First International Conference, DaSAA 2017, Chennai, India, January 4-6, 2017, Revised Selected Papers 1*. Springer Singapore, 2018.

[57]. Protege. Stanford University. Web. 14 Mar. 2024. http://protege.stanford.edu.

Funded by the European Union