



Advancing Sustainable Transport in Ireland

Document information	
Grant Agreement No	RDD907
Deliverable N° and title:	D4 - A comprehensive report on sustainable transport in Ireland
WP N° and title:	WP4 - Prioritization of data sharing areas for sustainable transport
Version N°:	V2.0 (Final)
Lead beneficiary:	UoG
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Submission date:	05/12/2024
Dissemination level:	SEN: Sensitive

Disclaimer:

The MaaS4IRL workshop has been supported with financial contribution from Sustainable Energy Authority of Ireland and the Department of Transport under the SEAI Research, Development & Demonstration Funding Programme 2023, Grant number 23/RDD/907.



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Document Summary

Document history			
Date	Version	Author(s)/Reviewer(s)	Comments
01/10/2024	V0.1	Fatemeh Ahmadi Zeleti	Prepared document outline.
07/10/2024	V0.2	Rafiqul Haque	Completed priority areas and the ROI of data sharing section.
30/10/2024	V0.5	Rafiqul Haque and Muhammad Abdur Razzak	Completed a roadmap for the Irish Mobility data space section.
10/11/2024	V1.0	Rafiqul Haque	Completed IMDS for key priority areas.
15/11/2024	V1.0	Rafiqul Haque	Completed introduction and conclusion sections.
16/11/2024		Edward Curry, Manohar Rao	Review and formatting.
30/11/2024	V2.0	Rafiqul Haque	Addressed feedback from internal reviewer, included executive summary, and added references. This is the final version.

Executive Summary

The transition to sustainable transportation is central to Ireland's efforts to reduce greenhouse gas emissions, achieve its climate objectives, and create an equitable and efficient mobility system. This report provides a detailed analysis and roadmap for the development and implementation of the **Irish Mobility Data Space (IMDS)**, a transformative initiative designed to enable secure and sovereign data sharing across stakeholders in the transport sector. The IMDS aims to foster collaboration, innovation, and evidence-based decision-making, addressing critical challenges such as emissions reduction, optimized resource use, and improved accessibility.

The report begins by examining the foundational concepts of data spaces and their relevance to Ireland's transport sector. It highlights the pivotal role of the IMDS in aligning with the European Data Strategy, emphasizing its capacity to facilitate interoperability, enhance data sovereignty, and promote value creation within the mobility ecosystem. Insights are drawn from comprehensive desk research and stakeholder workshops, which identify priority areas for data sharing, including **Mobility-as-a-Service (MaaS)**, **electric vehicle (EV) charging ecosystems**, **demand-responsive transit (DRT)**, **mobility hubs**, and **infrastructure planning**. These areas are strategically ranked based on their potential to drive sustainable transport solutions and maximize operational efficiency.

In this report, a phased implementation roadmap is presented, starting with a **Minimum Viable IMDS**. This phase focuses on deploying a sandbox environment to validate use cases, assess technical feasibility, and refine the data-sharing framework through iterative development and stakeholder feedback. The pilot project will serve as a proving ground, generating valuable insights to inform the transition to a **full-scale production IMDS**. The latter phase introduces comprehensive building blocks categorized into business, governance, legal, and technical components, ensuring alignment with national and EU regulatory frameworks, such as GDPR and the Data Governance Act.

The technical building blocks prioritize interoperability, data sovereignty, and trust while enabling value creation through secure and standardized data-sharing protocols. Governance frameworks emphasize transparency, accountability, and stakeholder collaboration, addressing critical issues such as data privacy, ownership, and usage rights. The business model, adapted from the standard digital goods framework, outlines pathways for creating economic value, fostering public-private partnerships, and ensuring financial sustainability.

This report identifies challenges such as interoperability, stakeholder engagement, data privacy, and compliance with legal and regulatory requirements. To address these issues, it proposes actionable strategies, including the adoption of standardized protocols, iterative testing within sandbox environments, and robust governance structures. These approaches aim to build trust among stakeholders and ensure the long-term scalability and adaptability of the IMDS.

The analysis highlights the transformative potential of data spaces in Ireland's transport sector. Practical use cases demonstrate how the IMDS can facilitate real-time multimodal transport integration, optimize EV charging infrastructure, and enable dynamic route planning for DRT services. The return-on-investment (ROI) framework highlights the economic, environmental, and social benefits of these initiatives, showcasing their alignment with Ireland's climate and mobility goals.

In conclusion, the IMDS is a critical enabler for Ireland’s transition to a sustainable, data-driven mobility ecosystem. By providing a secure, scalable, and collaborative platform, the IMDS positions Ireland to lead in the adoption of innovative transportation solutions that benefit citizens, businesses, and the environment. The phased implementation approach, supported by rigorous monitoring and evaluation, ensures that the IMDS adapts to emerging challenges and delivers measurable outcomes aligned with national and European priorities. This report serves as a comprehensive guide for policymakers, transport authorities, and stakeholders committed to advancing Ireland’s sustainable transport agenda.

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Acronym and Abbreviation Glossary

Abbreviation / Term	Description
NTA	National Transport Authority
MaaS	Mobility-as-a-Service
TFI	Transport for Ireland
TII	Transport Infrastructure Ireland
MDS	Mobility Data Space
ODRL	Open Digital Rights Language
VC	Verifiable Credentials
DQV	Data Quality Vocabulary
EVs	Electric Vehicles
Datex II	Data Exchange II
NeTEx	Network Timetable Exchange
SIRI	Service Interface for Real Time Information
INSPIRE	Infrastructure for Spatial Information in Europe
NGSI-LD	Next Generation Service Interface - Linked Data
OWL	Web Ontology Language
RDFS	Resource Description Framework Schema
JSON	JavaScript Object Notation
SKOS	Simple Knowledge Organization System
DCAT	Data Catalogue Vocabulary
CKAN	Comprehensive Knowledge Archive Network
W3C ODRL	World Wide Web Consortium Open Digital Rights Language
W3C DID	World Wide Web Consortium Decentralized Identifiers
W3C VC	World Wide Web Consortium Verifiable Credentials
OAuth 2.0	Open Authorization 2.0
GDPR	General Data Protection Regulation
MQTT	Message Queuing Telemetry Transport
DCAT-AP	Data Catalogue Vocabulary - Application Profile
MaaS Alliance	Mobility as a Service Alliance
NAPCORE	National Access Point Coordination Organisation for Europe
GTFS	General Transit Feed Specification
GBFS	General Bikeshare Feed Specification
TIDES	Transport Interoperability Data Exchange Specification
TODS	Transport Open Data Standard
TN-ITS	Transport Network Intelligent Transport Systems
ODRL	Open Digital Rights Language
DQ-VOCAB	Data Quality Vocabulary
eIDAS 2.0	Electronic Identification, Authentication and Trust Services 2.0
OID4VC	OpenID for Verifiable Credentials
DoT	Department of Transport

1 Introduction

The transition to sustainable transportation represents a critical element of Ireland's strategy to mitigate climate change, reduce greenhouse gas emissions, and foster a more equitable and efficient transportation ecosystem. Central to this endeavour is the adoption of advanced data integration frameworks, particularly through the development and implementation of Irish Mobility Data Space (IMDS). This platform will function as collaborative digital ecosystems, enabling the secure and efficient exchange of data among stakeholders. Such integration facilitates seamless coordination across diverse mobility services and systems. By harnessing the potential of the Irish Mobility Data Space, Ireland stands to unlock significant opportunities for reducing emissions, optimizing public transport operations, and advancing multimodal transport solutions. These efforts not only contribute to environmental sustainability but also drive innovation and operational efficiency within the national transport sector.

The **IMDS** is envisioned as a key initiative to realise a wide range of opportunities, fostering a connected ecosystem where public authorities, private mobility providers, and intermediaries (e.g., technology and data providers) to create data-driven transport solutions. It will enhance the efficiency of MaaS platforms, optimised EV charging infrastructure, and dynamic mobility hubs, all of which are essential for achieving Ireland's climate and sustainability goals. The IMDS offers a pathway to accelerate this transition by enabling informed decision-making, fostering innovation, and building trust among stakeholders. By addressing challenges such as data fragmentation, interoperability, and stakeholder coordination, the IMDS will empower Ireland to lead in sustainable mobility solutions.

1.1 Document Scope

This deliverable aims to identify the highest-priority areas for data sharing across the transport sector to accelerate the reduction of transport-related emissions. It aligns with the third objective of the MaaS4IRL project. Furthermore, it provides a comprehensive roadmap for implementing the Irish Mobility Data Space and offers actionable solutions to address both current and emerging challenges in the Irish Transport sector. The scope of the report encompasses the following key areas:

- **Identifying High-Impact Opportunities:** Highlighting areas where data-sharing initiatives can deliver substantial benefits in sustainability, operational efficiency, and user experience within the mobility ecosystem.
- **Addressing Mobility Challenges through IMDS:** Demonstrating the pivotal role of IMDS in resolving critical mobility issues through illustrative use cases, including real-time public transport data integration, the management of EV infrastructure, and the optimization of urban traffic flow.
- **Developing a Phased Roadmap for IMDS:** Proposing a stepwise approach to IMDS implementation, beginning with the creation of a sandbox environment, advancing to the development of a minimum viable IMDS, and culminating in the deployment of a fully operational IMDS. This roadmap includes detailed frameworks for governance, technical architecture, and business models, ensuring alignment with national and EU-level policies and regulatory requirements.

- **Addressing Implementation Challenges:** Identifying and discussing the technical, operational, and regulatory hurdles associated with the development and deployment of the IMDS.

Beyond the technical and operational aspects, this report delves into the broader societal and environmental implications of the IMDS. It emphasizes the importance of ensuring that the proposed solutions are equitable, scalable, and sustainable, thereby contributing to a transformative and inclusive mobility ecosystem.

1.2 Structure of the Document

The remainder of this deliverable is divided into five sections, each building upon the previous to provide a comprehensive understanding of the strategies for leveraging data sharing to advance sustainable transportation in Ireland.

Section 2 identifies critical areas where data sharing can generate substantial societal and economic benefits, with a particular focus on sustainability, accessibility, and innovation. It also presents an analysis of the returns on investment in the IMDS, highlighting its potential to deliver measurable value.

Section 3 explores the transformative potential of the IMDS in facilitating seamless multimodal integration across various transport modes, including buses, trains, and shared mobility services. It examines the role of the IMDS in enhancing MaaS platforms, enabling users to plan, book, and pay for integrated transport services through a single interface. Additionally, this section evaluates how the IMDS can optimize electric vehicle charging ecosystem by ensuring real-time availability of charging stations and improving grid stability. Practical use cases and discussions of technical and governance requirements provide insights into the feasibility and impact of these initiatives.

Section 4 outlines a detailed, phased roadmap for IMDS implementation. The process begins with the creation of a minimum viable IMDS in a sandbox environment and progresses toward the deployment of a full-scale production version. This section details governance structures that prioritize transparency, accountability, and equitable stakeholder participation. It also addresses regulatory compliance with national and EU-level standards, including GDPR and the Data Governance Act, and suggests strategies for managing cross-jurisdictional complexities. The proposed technical architecture emphasizes modularity and scalability, integrating secure data-sharing protocols and APIs to ensure resilience and interoperability. Strategies for fostering collaboration among public authorities, private entities, and citizens are also highlighted, ensuring alignment with Ireland's policy objectives and broader European data strategies.

Furthermore, Section 4 addresses potential technical, operational, and regulatory challenges in implementing the IMDS. It provides an in-depth analysis of barriers such as data privacy concerns, interoperability issues, and stakeholder alignment, along with actionable strategies to overcome these obstacles.

The **Conclusion section** synthesizes the report's findings and recommendations, underscoring the pivotal role of data sharing in advancing sustainable transportation in Ireland. It advocates for the establishment of a robust monitoring and evaluation framework to measure progress, assess impact, and refine the IMDS based on feedback from stakeholders. The report concludes by urging policymakers, transport authorities, private enterprises, and citizens to collaborate in creating a connected, efficient, and sustainable transport ecosystem.

2 Priority Areas and the ROI of Data Sharing

Key Takeaways from this Section

- Gaining insights into the priority areas of Ireland's transport sector.
- Understand the strategic ranking of these areas and their significance.
- Understand the role of strategic prioritization in advancing sustainable mobility solutions.

In Deliverable 3, a comprehensive analysis was undertaken to understand the role of data within key areas of Ireland's transport ecosystem, including MaaS, infrastructure planning, EV charging ecosystem, first-mile and last-mile freight delivery solutions, demand-responsive transit (DRT), and mobility hubs. The findings highlighted the critical importance of data sharing as an enabler of sustainable mobility solutions across these areas. Drawing on the insights gained from this analysis, the study identified and prioritized areas where data sharing exhibits the highest potential for reducing transport-related greenhouse gas emissions, thereby contributing to Ireland's broader sustainability objectives. Section 2.1 discuss the ranking of the priority areas.

This report provides a comprehensive evaluation of the return on investment (ROI) associated with data-sharing initiatives, highlighting their multifaceted benefits across economic, societal, and environmental dimensions. Section 2.2 presents ROI analysis of mobility data sharing.

2.1 Strategic Ranking of Priority Areas

Table 1 provides a comprehensive ranking of key priority areas, emphasizing their significance in fostering sustainable and efficient mobility solutions while aligning with Ireland's climate action goals. The table categorizes these areas based on their potential impact, relevance to current transport challenges, and alignment with national and EU-level policy objectives. In addition to ranking the priority areas, it highlights specific use cases that illustrate the practical application of each area and provides a rationale for their prioritization, grounded in evidence-based analysis. This structured approach ensures a clear understanding of the critical factors driving the prioritization and their contribution to advancing Ireland's sustainable mobility agenda.

Table 1: Ranking of priority areas for data sharing

Rank	Priority Area	Use Cases	Rationale
1	Mobility as a Service (MaaS)	Integration of public transport (e.g., Dublin Bus, Luas, DART), micromobility, car-sharing, and on-demand services into a seamless MaaS platform.	Data sharing is foundational to MaaS, enabling interoperability among diverse transport modes. Ireland's high car dependency makes MaaS critical for promoting public and shared transport.
2	Electric Vehicle (EV) Ecosystem	Sharing real-time EV charging data, pricing, grid capacity, and renewable energy alignment with drivers and operators.	Efficient data sharing is essential for building user confidence in EVs, optimizing charging infrastructure, and aligning with Ireland's renewable energy strategies.

3	First-Mile Last-Mile Freight Solutions	Collaborative platforms for sharing data on delivery schedules, vehicle locations, and micro-distribution hubs.	Shared data is vital for optimizing urban freight systems, reducing emissions from delivery vehicles, and alleviating congestion in cities like Dublin and Cork.
4	Demand-Responsive Transit (DRT)	Sharing real-time data on passenger demand, route optimization, and vehicle availability to offer flexible shared transport services.	DRT relies heavily on data sharing to dynamically allocate resources. It is particularly impactful for rural Ireland, where fixed-route services are inefficient.
5	Mobility Hubs	Sharing data across transport modes to enable seamless connections at centralized hubs (EV charging, bike-sharing, car-sharing, and public transport).	Data sharing enables real-time updates on service availability, enhancing the functionality and user experience of mobility hubs in urban and suburban Ireland.
6	Infrastructure Plannings	Using shared data for traffic modelling, active transport infrastructure planning, and identifying high-demand areas for parking or transit hubs.	While infrastructure planning benefits from shared data, its long-term implementation timeline makes it less immediately impactful for emissions reduction compared to other areas.

Justification of rankings

- *Mobility as a Service*
 - **Why Top-Ranked for Data Sharing?** MaaS depends entirely on the integration of diverse datasets, including public transport schedules, micromobility services, and payment systems. In Ireland, where private car usage dominates, a well-functioning MaaS system could drive significant modal shifts.
 - **Immediate Impact**
 - Reduces reliance on private vehicles by encouraging multimodal and shared transport use.
 - By reducing reliance on private vehicles, MaaS can alleviate urban congestion, lower emissions, and contribute to Ireland’s goal of a 50% reduction in transport emissions by 2030 as outlined in the Climate Action Plan.
 - In Ireland, extending the capabilities of the TFI Leap Card to a comprehensive MaaS platform could reduce emissions by encouraging public and shared transport use.
 - Provides a seamless, convenient mobility experience.
- *Electric Vehicle Ecosystem*
 - **Why Second?** Shared data on charging availability, grid capacity, and renewable energy usage is critical to scaling EV adoption. Ireland’s ambitious target of one million EVs by 2030 relies on public confidence in charging infrastructure.
 - **Immediate Impact**
 - Optimizes existing infrastructure, aligns charging schedules with renewable energy peaks, and encourages faster EV adoption.

- Reduces reliance on internal combustion engine (ICE) vehicles.
- Urban areas, where range anxiety and charging congestion are highest, present immediate opportunities for integration.
- *First-Mile Last-Mile Freight Solutions*
 - **Why Third?** Urban freight efficiency relies on shared data to optimize routes and consolidate deliveries. In Irish cities, freight accounts for a significant share of urban congestion and emissions.
 - **Immediate Impact**
 - Reduces emissions from delivery vehicles and alleviates urban traffic bottlenecks. Cities like Dublin, Cork, and Galway, where e-commerce and urban freight demand are high, present significant opportunities for integrating data-driven logistics solutions. Urban micro-distribution centres and electric cargo bikes can streamline delivery operations, reducing vehicle miles travelled.
- *Demand-Responsive Transit (DRT)*
 - **Why Fourth?** DRT depends on real-time data sharing to dynamically allocate vehicles based on user demand. It addresses Ireland's rural mobility gaps, reducing single-occupancy car trips in low-density areas.
 - **Immediate Impact:**
 - Replacing underutilized fixed-route services with DRT reduces emissions from empty buses while providing accessible mobility options. Rural areas and small towns in Ireland, where fixed-route public transport is less viable, can benefit significantly from DRT systems. Local Link services, for instance, could transition to data-driven DRT models, increasing accessibility while lowering emissions and operational costs.
- *Mobility Hubs*
 - **Why Fifth?** Data sharing is essential for real-time coordination of multiple transport modes at hubs, improving the user experience. In Ireland, mobility hubs can serve as critical transition points in urban and suburban areas.
 - **Immediate Impact**
 - Mobility hubs encourage modal shifts by making it easier for users to access sustainable transport options. Dublin, Cork, and Galway, where multimodal travel demand is high, are ideal locations for mobility hubs. These hubs can reduce emissions, support active transport modes like cycling, and enhance accessibility to public transport.
- *Infrastructure Planning*
 - **Why Sixth?** Shared data supports long-term infrastructure development, such as active transport networks and smart road designs. However, these projects often have longer implementation timelines compared to MaaS or EV systems.
 - **Long-Term Impact**
 - Provides a foundation for sustainable mobility solutions, but its benefits are realized over years rather than months.

2.2 Return of Investment Analysis

Data sharing serves as a catalyst for transformative outcomes in the transport sector by promoting sustainability, enhancing operational efficiency, and delivering improved user experiences. Its strategic implementation unlocks opportunities to optimize resources, reduce emissions, and foster innovation, thereby addressing pressing mobility challenges.

Table 2 provides an in-depth analysis of the return on investment (ROI) associated with each priority area. The table outlines the economic, environmental, and social impacts unique to Ireland’s transport ecosystem, showcasing how data sharing contributes to measurable benefits such as cost savings, emissions reduction, enhanced accessibility, and equitable mobility services. This analysis underscores the critical role of data sharing in aligning transport initiatives with Ireland’s climate targets and societal objectives.

Table 2: The Return On Investment for Priority Areas

Priority Area	ROI Drivers		
	Economic	Environmental	Social
Mobility as a Service	<ul style="list-style-type: none"> Increased public transport ridership boosts revenue for existing services like Dublin Bus, Luas, and DART. Multimodal ticketing boosts revenues for operators by encouraging users to choose public transport over private cars. Supports local tourism by providing seamless multimodal options for visitors. Reduces congestion costs. Supports local tourism by providing seamless multimodal options for visitors. 	<ul style="list-style-type: none"> Reduces emissions from private car dependency in cities like Dublin, Cork, and Galway by promoting public and shared mobility. Improves air quality in urban centres. 	<ul style="list-style-type: none"> Enhances user convenience through real-time information and seamless multimodal integration.
	Evidence	<ul style="list-style-type: none"> Whim in Finland: Demonstrated a 12% reduction in car use among users [1]. Increased public transport ridership generated higher revenues for transit operators. 	

		<ul style="list-style-type: none"> • Japan’s MaaS in Shizuoka: Increased regional economic activity by improving tourist mobility [2]. 	
Electric Vehicle (EV) Ecosystem	<ul style="list-style-type: none"> • Decreases reliance on imported fossil fuels, saving millions annually. • Optimizes utilization of public investments in EV charging infrastructure. • Aligns EV charging with renewable energy peaks, reducing grid strain and energy costs. • Maximizes return on capital investments. 	<ul style="list-style-type: none"> • Significant GHG reductions by transitioning from internal combustion engines to EVs. • Integration of renewable energy reduces lifecycle emissions from EV operations. 	<ul style="list-style-type: none"> • Improves public confidence in EVs, encouraging adoption and fostering energy independence.
	Evidence	<ul style="list-style-type: none"> • The Open Charge Point Protocol (OCPP) [44] has enabled smoother EV charging integration globally. In Ireland, expanding EV charging networks and linking them with MaaS platforms could significantly reduce transport emissions while supporting green jobs in the EV infrastructure sector. • Netherlands’ EV Infrastructure: Achieved a 25% increase in charging station utilization through real-time data integration [3]. • California’s ChargePoint Network: Demonstrated enhanced user satisfaction and EV adoption rates with dynamic charging availability data [4]. 	
First-Mile Last-Mile Freight Solutions	<ul style="list-style-type: none"> • Lower delivery costs for businesses and reduced urban congestion costs. • Lower congestion costs in urban areas by minimizing freight vehicle trips. 	<ul style="list-style-type: none"> • Reduced emissions from electrified last-mile delivery. 	<ul style="list-style-type: none"> • Improved urban air quality and reduced traffic disruptions. • Enhanced efficiency benefits businesses and consumers.
	Evidence	<ul style="list-style-type: none"> • Dublin’s Micro-Distribution Pilot: Reduced van trips and emissions in city centres through shared delivery hubs [5]. • London’s Clean Air Freight Initiatives: Achieved a 10% reduction in urban freight 	

		emissions through data-enabled consolidation [6].	
Demand-Responsive Transit (DRT)	<ul style="list-style-type: none"> Reduces operational costs for transit providers by replacing underutilized fixed-route services. Supports rural economies by improving accessibility to jobs, education, and healthcare. 	<ul style="list-style-type: none"> Lower emissions from single-occupancy car trips in rural and low-density areas. Optimized routes minimize fuel consumption. 	<ul style="list-style-type: none"> Enhanced accessibility in rural Ireland, reducing isolation and promoting equity. Promotes community well-being by improving access to essential services.
	Evidence	<ul style="list-style-type: none"> Finland’s Kutsuplus System: Reduced single-occupancy vehicle trips by 30% in urban Helsinki [7]. Australia’s DRT in Logan City: Improved transport accessibility by integrating user demand and dynamic routing [8]. 	
Mobility Hubs	<ul style="list-style-type: none"> Increased revenue from shared mobility services and reduced parking infrastructure costs. Reduced costs for road maintenance and parking infrastructure as fewer private cars are used. 	<ul style="list-style-type: none"> Emissions reductions from modal shifts away from private vehicles. 	<ul style="list-style-type: none"> Improved urban and suburban connectivity, enhancing commuter satisfaction. Promotes urban development and smart city initiatives.
	Evidence	<ul style="list-style-type: none"> Berlin’s Jelbi Hubs: Reduced car dependency by integrating multiple transport modes [9]. Los Angeles Mobility Hub Pilot: Increased micromobility usage by 30% through real-time app integration [10]. 	
Infrastructure Planning	<ul style="list-style-type: none"> Supports targeted investment in active transport infrastructure, reducing long-term road maintenance costs. Promotes tourism by improving walking and cycling infrastructure in scenic areas. 	<ul style="list-style-type: none"> Reduces reliance on cars by improving infrastructure for cycling, walking, and public transport. 	<ul style="list-style-type: none"> Enhances safety and accessibility for pedestrians and cyclists. Encourages active travel, improving public health outcomes.

	Evidence	<ul style="list-style-type: none"> • Copenhagen’s Smart City Planning: Data-driven bike lane expansion increased cycling rates by 20%, reducing emissions [11]. • Singapore’s Smart Urban Mobility Program: Leveraged data to optimize road layouts and reduce congestion by 15% [12].
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3 IMDS for Key Priority Areas

Key Takeaways from this Section

- Understand how mobility data spaces align with Ireland’s climate goals and broader sustainability objectives.
- Discover the role of mobility data spaces in five key areas of Ireland’s transportation sector, including Mobility as a Service, EV charging ecosystems, demand-responsive transit, mobility hubs, and infrastructure planning.

We conducted a comprehensive and detailed analysis of the use of data spaces within the identified priority areas, focusing on their potential to drive sustainable transport solutions and improve operational efficiency. This analysis examined how mobility data space can address key challenges, such as emissions reduction, enhanced accessibility, and optimised resource use, while aligning with Ireland’s climate goals.

3.1 Mobility as a Service

Ireland has had a significant and largely unchanged transport network up to now, but that is no longer the case as demand for integrated, sustainable, and customer-focussed mobility options accelerate. Connecting the IMDS with the MaaS platform for multimodal trip planning and booking would be a great solution by allowing secure and interoperable data sharing between different (public and private) transport services. The IMDS, however, enables live data sharing amongst transportation operators, city planners, and service providers making planning or booking a journey more real-time responsive seamless and efficient.

Example Scenario

Take the case of an example commuter — Bray suburb to Dublin city centre. You, as a user of MaaS app (using IMDS), plan your trip. The platform illustrates the most cost-effective modes combination—a DART train to the downtown area and a shared e-scooter for the last mile to their workplace. Integrating IMDS allows the app with real-time train schedule check and e-scooter availability check, updating the user on delay or less vehicle available before they start their journey. IMDS allows for seamless data flow from both public and private providers, optimizing the commuter journey for time and convenience.

Role of IMDS in Multimodal Trip Planning

- **Facilitating Uninterrupted Transport Mode Data Interoperability:** The IMDS encourages standardized data formats and protocols in order to ensure seamless interoperability across

mode, including the Dublin Bus, Iarnród Éireann (Irish Rail), bike-sharing operators, e-scooter providers and others. IMDS provides access to real-time data across these services, allowing for journey planning, scheduling, and ticketing to be integrated and without delay so that users can have a reliable multimodal choice. This interoperability ensures data isn't siloed and can be accessed by more users, particularly in urban centres.

- **Enabling Data-Driven, Real-Time Decision-Making for Users and Transit Agencies:** Users and transit authorities can share information (availability, real-time schedule, travel disruption) via IMDS. If a train line is delayed, the platform can notify users immediately and provide alternative transport options. Public authorities can also use this data for demand forecasting, adjusting the frequency of buses or trams based on travel peaks, and identifying where additional services are needed. This dynamic response capability streamlines business operations and enhances the overall user experience.
- **Greater EU-Style Privacy and Data Sovereignty:** This is the answer because Ireland abides to the EU's GDPR regulations – protecting user privacy in their heart. With IMDS, data providers only share what needs to be shared for acting services or otherwise, keeping a hold of their data. Privacy-preserving features inside IMDS allow for secure sharing of the data stored by different stakeholders — e.g., between ride-hailing and bike-sharing providers in compliance with user consent and regulations. It helps in making sure that everyone has faith in data providers, users and authorities which leads to a more secure data ecosystem.
- **Encouraging Cooperation between Public and Private Sector for a Sustainable Mobility Ecosystem:** The IMDS provides a common platform for public transit authorities, bike-sharing programs, e-scooter companies and ride-hailing providers to collaborate while safeguarding regional interests. The IMDS creates a transparent data-sharing partnership mechanism, which brings mutual value to service providers who can then collaborate in co-developing solutions aligned with Ireland climate and sustainability targets by exchanging insights. Optimally connecting urban and regional transit systems is a vital part of building the connected, multimodal, transit network that has the potential to meet Ireland's diverse mobility needs.

IMDS combined with multimodal trip planning brings a lot of value to the ecosystem. Mobility operators have extended reach and efficiency, transportation authority's access highly valuable data to facilitate sustainable planning, and end-users enjoy a seamless, reliable travel experience with privacy safeguarded. Collectively, these advantages support Ireland's vision of a seamless, integrated, and sustainable mobility ecosystem.

3.2 EV Charging Ecosystem

Ireland's commitment to reducing greenhouse gas emissions and fostering sustainable mobility aligns with the growth of EVs across the country. With currently over 2,400 public charging points across the country, Ireland's network of publicly accessible EV charging stations continues to grow as the range of available EV cars also expands, as of February 2024. But deployment of enroute charging infrastructure is challenging and requires close consideration of factors including optimal station siting, local electricity grid capacity, the service operating models that can be sustained in practice and financial support for essential deployment in remote regions. Therefore, a strategically planned EV charging network is essential to support EV adoption, alleviate range anxiety, and reduce reliance on fossil-fuel-based vehicles.

The IMDS can help enable secure, standardized data exchange between the stakeholders participating in it such as municipalities, EV charging operators, energy providers and/or transit authorities when planning for EV infrastructure. The IMDS provides these participants with both real-time and historical mobility data from which they can leverage to make informed decisions about siting, sizing, and operating EV charging stations across Ireland.

Example Scenario

In Galway, a city planner is tasked with growing the EV charging network to keep pace with demand peaking. With sharing data through IMDS, the planner can examine how people move about and determine popular commuting corridors, areas with high levels of movement activity, or hotspots for increasing EV penetration. In this instance, the data reveal that an important area right off of a business district is not well-served by charging infrastructure. The planner then prioritizes this site for new chargers and continually collects usage data over time to see if further coverage is needed. The planner can even dynamically manage charging capacity, using real-time data from IMDS to adjust plans as current demand develops.

Role of IMDS in EV Charging Network Planning

- **Data-Driven Site Selection for Charging Stations:** With data on mobility trends, human behaviour regarding high-demand routes and bus stops, IMDS provides an alternative for planners to strategically place EV charging stations for maximum utility. By analysing peak travel times, common destinations, and EV density data, municipalities can better determine optimal locations for charging infrastructure that will be widely used, reducing range anxiety and encouraging broader EV adoption.
- **Real-Time Demand Monitoring and Capacity Management:** Using IMDS, municipalities and energy providers gain real-time access to charging station data such as occupancy rates, wait times, and frequency of use for the different charging stations. This real-time data helps manage the total capacity of charging stations by enabling operators to increase the number of charging points at each station or deploy mobile chargers to high-demand areas during peak times.
- **Integration with Multimodal Mobility Hubs:** IMDS enables seamless integration of EV charging points within multimodal mobility hubs, providing EV drivers with easy access to public transit, bike-sharing, or e-scooter options. This integration supports last-mile connectivity and allows users to switch from private EVs to other sustainable modes for the remainder of their journey, reducing congestion in urban areas.

IMDS enables to develop a scalable, data-driven solutions that is in step with Ireland's ambition to develop an EV charging network that advances the country's environmental and mobility objectives. With real-time and historical data insights on both where and how many EVs are used, municipalities and energy providers can not only place the charging stations strategically but also build an ideal capacity management system to ensure the network benefits from increased EV demand in the future. The technology powering IMDS-enabled EV charging infrastructure not only facilitates and encourages electric vehicle adoption but also enhances user convenience within an eco-friendly, multimodal transportation system for Ireland.

3.3 Demand Response Transit

Ireland's commitment to sustainable mobility and reducing greenhouse gas emissions aligns closely with the implementation of demand-responsive transit (DRT) solutions. As an innovative transportation model, DRT bridges the gap between fixed-route public transit and individual mobility, offering on-demand, flexible services tailored to passenger needs. However, implementing DRT at scale requires addressing key challenges, such as optimal routing, dynamic capacity management, and integration with other transport modes. These efforts must also account for operational efficiency, equitable service provision, and sustainability goals.

Example Scenario

In Cork, a local transit agency is tasked with addressing transit deserts—areas underserved by traditional fixed-route services. Using IMDS data, the agency identifies neighbourhoods with low public transit coverage and high concentrations of commuters. By analysing real-time mobility patterns, the agency discovers that many residents rely on private vehicles for short trips to nearby transit hubs. Based on these insights, the agency launches a DRT service that dynamically adjusts routes to meet demand, picking up passengers in these underserved areas and connecting them to transit hubs more efficiently. Over time, usage data collected via the IMDS helps refine service patterns, optimize routes, and enhance the overall user experience, ensuring that the DRT system evolves alongside changing mobility needs.

Role of IMDS in Demand-Responsive Transit

- **Dynamic Route Optimization:** The IMDS will provide access to mobility trends and user demand data, enabling transit operators to design routes dynamically based on real-time needs. By analysing peak travel times, common destinations, and areas of high passenger density, DRT services can offer flexible routing that maximizes efficiency and minimizes wait times, improving user satisfaction.
- **Capacity Management and Resource Allocation:** With real-time data from the IMDS, transit agencies will be able to monitor vehicle occupancy, trip requests, and service frequency, allowing for dynamic adjustments to fleet size and deployment. This helps optimize resource use by ensuring vehicles are deployed where demand is highest while avoiding underutilization in low-demand areas.
- **Integration with Multimodal Transit Options:** The IMDS will facilitate the integration of DRT services within Ireland's broader multimodal transit network. This includes seamless connections to buses, trains, and active mobility options like bike-sharing and e-scooters. Such integration enhances last-mile connectivity and encourages a shift away from private vehicle use, reducing urban congestion and emissions.

By enabling data-driven decision-making, the IMDS empowers transit operators to develop scalable and efficient DRT solutions that align with Ireland's sustainability and mobility goals. With insights derived from both real-time and historical data, stakeholders can strategically deploy DRT services to underserved areas, enhance service reliability, and ensure equitable access for all users.

3.4 Mobility Hub

Strategically located mobility hubs in Ireland can assist in creating surroundings that promote accessibility, reduce urban congestion, and balance transport modes. These hubs consolidate various

transport modes, including public transit, bike-sharing, e-scooters, and car-sharing, into a single place that aims to facilitate seamless mode transfers while limiting private vehicle dependence. Using the IMDS, transport authorities and municipalities can access real-time and historical mobility data, giving them the opportunity to plan, optimize, and manage their mobility hubs under actual demand and usage patterns. Such an approach ensures that the mobility hubs are strategically placed for maximum impact and serve the country's increasing variety of commuter needs.

Example Scenario

Cork — A planner has to create a new mobility hub near a university and busy commercial district. They use IMDS to examine commuter data, travel peak hours, and dominant modes of transport in the area. Data shows significant bike-sharing and ride-sharing activity during the morning and evening rush hours. The planner, in turn, can design the hub with sufficient bike/e-scooter docks and EV charging stations through to dedicated drop-off zones for ride-hailing services. Using IMDS for real-time data sharing, hub managers observe vehicle availability throughout the day to ensure their hub is in line with user demand and operationally efficient.

Role of IMDS in Mobility Hub Development

- **Data-Driven Site Selection for Mobility Hubs:** IMDS will give authorities visibility into the full range of mobility demand, including where transit is most needed, where and how many people are travelling at any point in time, and what first/last-mile needs exist. This data will allow municipalities to see where there is the most demand for a mobility hub, such as near major transit stations, universities, business districts, and residential areas underserved by public transit.
- **Supporting Multimodal Connectivity and User Convenience:** IMDS will enable pulling together the various data sets that come from all the transport providers your hub serves, allowing seamless mode transitions. For example, bus riders arriving at a hub could view the availability of bikes or e-scooters in real time via the IMDS-connected MaaS platform. It thereby will make sure users always have reliable options for their last-mile trips, which adds to user convenience and increases the likelihood of public transit usage.
- **Enhanced Resource Allocation for Sustainable and Accessible Transportation:** Planners can tap into collective data through IMDS and use insights to determine where all the hubs should be located and what they should offer — for instance, EV charging stations, bike-sharing, or wheelchair-accessible services. Such focus will allow the hub resources to align better with community requirements and also contributes toward the sustainability goals of Ireland by promoting green transport.

The incorporation of IMDS when developing mobility hubs in Ireland allows data to drive the actualization of efficient, accessible, and sustainable transport hubs. To plan and design hubs for optimal demand and multimodal linkages, and to help reach environmental goals in Ireland, transport authorities and municipalities can take advantage of real-time and historical mobility data. By making travel more efficient and encouraging public transit, IMDS-powered mobility hubs can play a significant role in Ireland's transformation into a less car-dependent society, leading to a connected, greener transportation network for the nation.

3.5 Infrastructure Planning

Ireland has seen urbanization, population growth, and changing mobility demand to make it evident that its transportation infrastructure needs an adaptation. IMDS creates a path for urban planners and transportation authorities to receive standardized, anonymized real-time mobility data from public and private mobility providers by enabling secure data sharing. The sharing of this data allows for infrastructure planning that reflects usage patterns, sustainable development, and effective resource allocation. IMDS will help municipalities to understand mobility trends, allowing them to predict infrastructure plans in a much smarter way.

Example Scenario

In Dublin, a planner has to account for improved transit access as suburban neighbourhoods near the city keep growing. Accessing real-time and historical data from the IMDS, they examine travel patterns in areas of interest — including how often travellers are using bike-share trips or e-scooters, and how many people are taking public transit. Analysis of that data shows a disconnection between a suburban community with growing transit demand and the nearest transit hub. In response, the planner prioritizes building a bike lane and more park-and-ride options for the region. As mobility data space enables data sharing across all projects, this decision is rooted in real user behaviour and not just assumptions—meaning resources can be allocated effectively.

Role of IMDS in Infrastructure Planning

- **Access to Real-Time Mobility Data for Informed Decision-Making:** IMDS enables access to high-quality and secured data set around anonymized sources, from these different mobility providers of ride-sharing, public transit, bike sharing, and e-scooters. IMDS enables local governments to aggregate this data in a consistent format, providing insights into mobility patterns including peak times of use, high-usage corridors, and hotspots of transit demand. This information supports targeting infrastructure development based on decisions that reflect reality in travel behaviour.
- **Enhanced Ability to Identify Infrastructure Gaps and High-Demand Areas:** IMDS enables urban planners to pinpoint where infrastructure improvements are a priority. If data from bike-sharing and e-scooter services, for instance, indicates lots of use at or near certain transit hubs in a municipality, that might spur the city to create additional bike lanes surrounding those transit hubs to enhance connectivity. In a similar sense, MDS data shows us where residents are currently going but not getting service, which can help planners to better provide services or to site new facilities.
- **Long-Term Planning with Historical Mobility Data:** With IMDS enables accessing various data sources on the evolution of mobility patterns, organizations can discover seasonal demand trends, impacts of population growth, and changes in travel behaviour over time. That data gives planners an insight into trends that span the longer term and allows them to plan infrastructure investments with an eye towards long-term growth. Having a built understanding around past and current usage allows authorities to much better predict what the future looks like, building infrastructure that evolves along with its population and travel patterns.
- **Data-Driven Sustainability Planning and Environmental Impact Reduction.** IMDS further enables data from low-carbon vehicle adoption to be shared in a way that municipalities can use it to rank projects on their environmental mitigation potential. Using information from public

transportation, bike sharing, and e-scooter providers, planners can also recognize where expanding sustainable infrastructure — like Electric Vehicle charging stations, bicycle lanes, and pedestrian zones — is an opportunity. This complements the Climate Action Plan with respect to diminished car dependence and also greening mobility in Ireland.

Mobility Data Spaces equip city planners and municipalities in Ireland with the actionable, evidence-based intelligence needed to facilitate data-driven decision-making on transportation infrastructure that ultimately drives efficient, sustainable, and responsive planning. IMDS enables authorities to allocate resources more effectively, target projects based on real-time and historical mobility data, and contribute towards the sustainability goals of Ireland by providing access to detailed data which will allow for improved urban planning. IMDS will be a framework for designing infrastructure ready for the future, built to help Irish city-builders respond to long-term national mobility and environmental goals.

4 A Roadmap for the Irish Mobility Data Space

Key Takeaways from this Section






- Understand the phased approach for implementing the Irish Mobility Data Space (IMDS), starting with a Minimum Viable Data Space and progressing to a full-scale production data space.
- Gain insights into how the roadmap aligns with national and European strategies for data sharing and sustainable mobility.
- Recognize the importance of iterative development, stakeholder collaboration, and strategic prioritization in achieving a scalable and robust IMDS.
- Understand the critical role of sandbox environments in validating use cases, refining requirements, and building confidence among stakeholders.

In **Deliverable 1**, desk research explored MaaS, data-sharing technologies—especially Mobility Data Spaces — and regulatory frameworks. It highlighted Mobility Data Space (MDS) as a key enabler for data-sharing solutions in Europe, aligning with the European Data Strategy, and emphasized the importance of robust regulatory frameworks for trusted data-sharing ecosystems.

In **Deliverable 2**, stakeholder workshops provided insights into Ireland’s transport sector, the challenges and opportunities of MaaS, data-sharing constraints, and regulatory considerations, offering a grounded perspective to complement the research. **Deliverable 3** built on these insights to develop guidelines focused on trusted data-sharing mechanisms and governance frameworks. In that deliverable we recommended MDS as the ideal data sharing solution for Ireland, ensuring alignment with the European Data Strategy while addressing local needs.

In this section, we outline a two-phased roadmap for the implementation of the IMDS to facilitate data sharing within Ireland’s transport sector (*See Figure 1*). The first phase emphasizes the development of a **minimum viable mobility data space**, serving as a foundational prototype for testing and evaluation. This is followed by the second phase, which involves the deployment of a **full-scale data space**, enabling comprehensive and scalable data-sharing capabilities across the sector.

Figure 1: The Roadmap of Irish Mobility Data Space

CATEGORIES	PHASE 1 Minimum Viable IMDS 	PHASE 2 Full-Scale IMDS 
 OBJECTIVES	<ul style="list-style-type: none"> The objective of the Minimum Viable Irish Mobility Data Space is to establish a foundational data-sharing platform within a controlled sandbox environment that enables stakeholders to experiment, evaluate, and validate the feasibility of data spaces in Ireland's transport ecosystem. 	<ul style="list-style-type: none"> The objective of the full-scale Irish Mobility Data Space (IMDS) is to operationalize a robust, scalable, and interoperable data-sharing ecosystem that enables secure, efficient, and sovereign exchange of mobility-related data across all stakeholders in Ireland's transport sector.
 ACTIVITIES	<ul style="list-style-type: none"> Align with minimum number of stakeholders Develop a simple use case Setup a sandbox environment Develop minimum viable IMDS Onboard participants Piloting the data sharing 	<ul style="list-style-type: none"> Design and implement the business building blocks Design and implement the governance building blocks Design and implement the legal building Design and implement interoperability building blocks design and implement data sovereignty building blocks Design and implement data value creation building blocks
 DELIVERABLES	<ul style="list-style-type: none"> A lightweight data space tested for the mobility sector in Ireland A report explaining the experience of mobility data sharing using data space technologies. 	<ul style="list-style-type: none"> A comprehensive data space for sharing data of the Irish transport sector.

4.1 Minimum Viable IMDS in the Sandbox Environment

The Minimum Viable Irish Mobility Data Space (IMDS) represents a prototype implementation of a data space that use open-source technologies. This setup enables stakeholders to assess whether data spaces are a viable, efficient, and effective solution for facilitating data sharing within Ireland’s transport sector. This section describes the implementation of a minimum IMDS.

4.1.1 Align with the Stakeholders and Use Case Development

The development of a **minimum viable IMDS** requires two key types of stakeholders: a **development partner** and **participants** to engage with the IMDS. Robust implementation of the IMDS necessitates collaboration with experts proficient in data space technologies. The **University of Galway**, through its Insight SFI Research Centre for Data Analytics, emerges as a pivotal development partner in this endeavour. As a core participant in the European Commission's Data Space Support Centre, the University contributes to the design principles for next-generation data spaces, demonstrating its leadership and expertise in this domain.

Engaging with the University of Galway provides the IMDS initiative access to specialized knowledge and established networks, enabling the development of a minimum viable data space within a controlled **sandbox environment**. This partnership ensures alignment with national priorities and European data strategies, promoting secure, efficient, and innovative data sharing across Ireland's transport ecosystem.

To simplify the initial implementation, the **minimum viable IMDS** is designed to avoid excessive complexity by involving a limited number of participants. We strongly recommend engaging participants from key **public service stakeholders**, including but not limited to:

- **Transport Operators:** Irish Rail, Dublin Bus, Dublin Bikes, and e-Scooter providers.
- **Public Mobility-as-a-Service Operators:** TFI Live App.
- **Government Agencies:** Department of Transport, National Transport Authority (NTA), and Sustainable Energy Authority of Ireland (SEAI).

These participants will gain access to the sandbox environment to experiment with shared datasets, explore specific use cases, and test interoperability. The sandbox fosters collaboration by providing a shared platform to identify and leverage data-sharing opportunities, address technical challenges, and refine the system based on practical insights. By involving these key stakeholders, the minimum viable IMDS can effectively demonstrate the potential of data spaces to transform Ireland's transport sector.

The stakeholders will collaboratively develop **use cases** to demonstrate the potential and functionality of the IMDS. Two areas with significant potential for developing impactful use cases are **MaaS** and **infrastructure planning**. These domains align closely with Ireland's transport objectives and offer opportunities to address pressing challenges through data sharing.

We recommend using the **example scenarios of Mobility-as-a-Service (Section 3.1)** and **infrastructure planning (Section 3.4)** as foundational references for designing suitable use cases for the minimum viable data space. These scenarios provide practical and context-specific insights, enabling stakeholders to test interoperability, refine data-sharing frameworks, and validate the benefits of the IMDS in a sandbox environment. By focusing on these high-impact areas, the initiative can effectively illustrate the transformative potential of data spaces in advancing sustainable and efficient transport solutions in Ireland.

4.1.2 Setting up a Sandbox Environment

A sandbox environment using **Eclipse Dataspace Components (EDC)** [42] provides a secure and controlled platform for testing and validating data-sharing frameworks. This setup is essential for assessing the feasibility of data-sharing mechanisms in a controlled setting while minimizing risks associated with live system integration. The features and activities involved in establishing this sandbox environment ensure a robust and flexible foundation for developing the IMDS.

A key feature of the sandbox is its controlled and secure setup. Operating in isolation from production systems, it ensures that experimentation does not interfere with live operations or compromise sensitive data. The sandbox environment allows stakeholders to test the sovereign data-sharing capabilities of the EDC framework, ensuring compliance with GDPR and robust data governance policies. By providing a secure and independent testing ground, it fosters confidence in the technical and regulatory viability of data-sharing initiatives.

The sandbox environment will be built on an open-source technology foundation, leveraging the modular and flexible tools offered by the **EDC**. This framework simplifies the implementation and management of data spaces by incorporating pre-built functionalities for critical processes, including secure data exchange, contract negotiation, identity management, and data usage control. These capabilities streamline the testing process and enable stakeholders to focus on validating use cases and refining data-sharing protocols.

To establish the sandbox, the development partner will undertake several key activities. The first step involves defining the objectives of the sandbox. This includes identifying specific goals, such as testing secure data exchange, validating use cases like MaaS and infrastructure planning, and fostering

collaboration among stakeholders. Additionally, the relevant datasets and participants for the initial phase must be determined to ensure alignment with the overarching objectives of the IMDS initiative. The next phase is preparing the infrastructure. This involves deploying a cloud-based or on-premises setup with sufficient resources to support scalability, security, and data processing requirements. Development tools such as Docker and Kubernetes will be employed for containerization and orchestration, ensuring efficient management of the sandbox environment. The Eclipse Dataspace Components will be installed and configured as the foundational framework, enabling the implementation of key data-sharing functionalities.

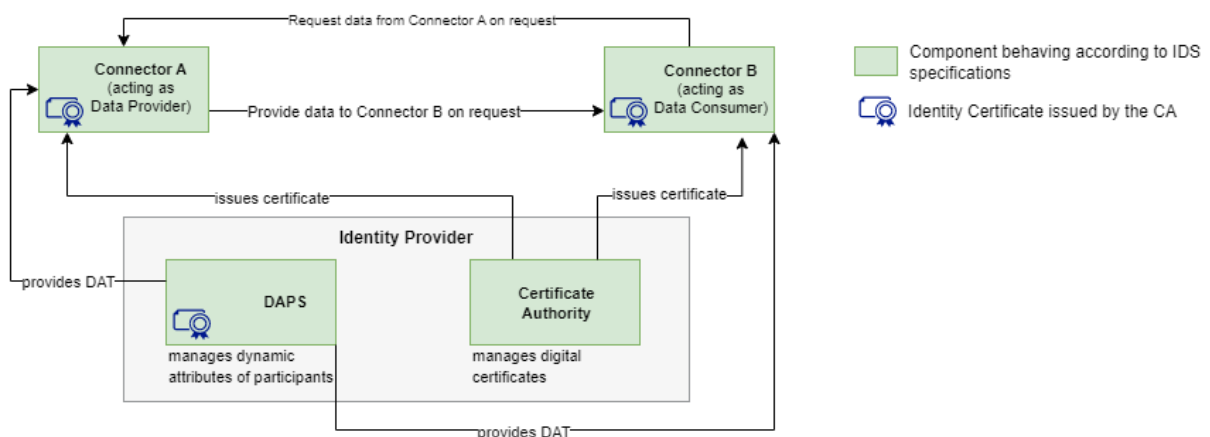
By incorporating these elements, the sandbox environment serves as a critical platform for evaluating and refining the data-sharing frameworks required for the IMDS. It ensures alignment with technical, operational, and regulatory standards, providing stakeholders with a reliable testing ground for collaborative experimentation and iterative development. This structured approach establishes a robust foundation for the future scalability and operational success of the IMDS.

4.1.3 Develop Minimum Viable IMDS

The **Minimum Viable IMDS** is designed to expedite the development and implementation of data-sharing frameworks, focusing on essential functionalities while avoiding the complexities of a fully developed system. This approach enables stakeholders to begin with a functional prototype that ensures secure and sovereign data exchange. By facilitating iterative testing and refinement, the Minimum Viable IMDS allows the development team to address assumptions, align with stakeholder needs, and refine system requirements based on real-world feedback. This ensures the data space aligns with the specific requirements of Ireland’s transport sector.

Key elements of the Minimum Viable IMDS include two connectors—one acting as a data provider and the other as a data consumer—forming the backbone of secure data exchange (See Figure 2 sourced from [41]). An identity provider, incorporating a Dynamic Attribute Provisioning Service and a Certificate Authority, ensures secure and authenticated interactions. The development platform relies on the open-source **Eclipse Data Space Connector**, providing a modular and scalable foundation. Additional components, such as a metadata broker, app store, clearinghouse, or vocabulary provider, can be integrated to extend the functionality of the Minimum Viable IMDS. These optional features enable advanced capabilities, such as dataset searchability, improving the platform’s versatility.

Figure 2: Key Components of Minimum Viable IMDS



The **integration of test datasets** is a crucial step in establishing the Minimum Viable IMDS. Anonymized or synthetic datasets relevant to Mobility-as-a-Service (MaaS), such as public transport schedules and ride-sharing data, as well as infrastructure planning datasets like traffic flow and road network conditions, will be used. These datasets will be consistently formatted and fully compliant with data privacy regulations, ensuring that testing adheres to both ethical and legal standards.

Stakeholder engagement is equally important. The **onboarding of stakeholders** includes providing access to sandbox participants, such as transport operators, government agencies, and MaaS providers. Workshops and training sessions will be conducted to familiarize these stakeholders with the sandbox environment and its functionalities, fostering collaboration and active participation.

The Minimum Viable IMDS will also focus on **testing minimum viable use cases**, based on real-world scenarios. For MaaS, use cases will involve the real-time integration of multimodal transport data, such as buses, trains, and bikes, to streamline mobility services. For infrastructure planning, use cases will focus on optimizing EV charging infrastructure by leveraging traffic and energy grid data. The Eclipse Data Space Connector's policy and contract management tools will ensure secure and compliant data-sharing practices during these tests.

The sandbox environment supports **iterative development and testing**, enabling developers and stakeholders to continuously refine features, validate assumptions, and adapt system requirements. This process ensures that the data-sharing framework evolves in response to real-world feedback, maintaining alignment with operational needs.

The iterative development and testing process is a cornerstone of the Minimum Viable IMDS. The sandbox environment facilitates continuous testing and refinement, allowing developers and stakeholders to validate the ecosystem's assumptions and adapt the design to meet emerging needs. This iterative approach ensures that the system remains aligned with technical and operational requirements while building confidence in its capabilities, such as secure data transfer, real-time analytics, and seamless integration with existing systems.

4.2 Full-Scale Production IMDS

The successful implementation of the **minimum viable data space** represents a pivotal milestone in progressing toward a fully operational, **full-scale production data space** for Ireland's mobility sector. This section outlines a comprehensive blueprint comprising the essential **building blocks** required to realize a production-ready Mobility Data Space. The blueprint leverages the foundational methodologies developed by the **Data Space Support Centre** [43] and is carefully tailored to address the unique needs, challenges, and opportunities within Ireland's transport ecosystem.

The framework for the IMDS integrates **business and organizational building blocks**, categorized into **business, governance, and legal** components. These elements provide the structural foundation to ensure operational efficiency, stakeholder alignment, and regulatory compliance. In addition, **technical building blocks** are organized into key categories, including **interoperability, data sovereignty and trust, and value creation enablers**. Together, these building blocks form a cohesive architecture designed to deliver a robust, secure, and scalable data-sharing environment for Ireland's mobility sector.

By leveraging best practices in data space design and incorporating insights gained during the deployment of the minimum viable IMDS, this blueprint outlines a robust framework for scaling data-

sharing capabilities. It emphasizes secure and sovereign data exchange, fosters stakeholder collaboration, and supports Ireland's sustainability and mobility objectives. This approach ensures that the full-scale IMDS is not only technically sound but also aligned with national and European strategies for digital transformation and sustainable transport development.

4.2.1 Business

This section explores the business building blocks of the Irish Mobility Data Space, outlining the foundational elements necessary for its successful implementation. It provides an in-depth analysis of the essential requirements for designing and operationalizing these business building blocks, ensuring they align with the specific needs of Ireland's transport sector.

4.2.1.1 Sustainable Business Model

A data space is inherently different from the business ventures run by a single organization, as its worth lies in the model whereby all involved organizations share, access, and use data. Achieving a viable business model for an Irish mobility data space will require integration with technology utilized by the data space, alignment among stakeholders as well as alignment to the governance framework. It is important to note that there is no established reference business model for data spaces. In this section, we propose a business model for the IMDS, adapted from the standard business model for digital goods. Here is the breakdown of how this business model is uniquely structured, followed by the key details on the components.

A good incentive mechanism will be one of the cornerstones to unlock an Irish Mobility Data Space — ensuring that a broad spectrum of stakeholders is compensated and incentivised to actively participate in the data space from public transport operators, private mobility providers and technology companies alike. Such an approach could include monetary and non-monetary incentives as they have been effective for individual motivation, whereby the two components would synergize to promote active participation by those involved in the data-sharing and data-exchanging processes. The following is a description of different financial and non-financial incentives relevant to the Irish Mobility Data Space.

Monetary Incentive Models

- **Demand and Supply Model:** The model establishes a marketplace between data providers (e.g., public transit operators) and data recipients (e.g., mobility app developers), allowing for a market-driven approach. The autoregressive nature of price change (through demand and supply) also creates incentives for data publishers to produce publish more useful, high-value, or in-demand data while allowing data consumers to pay only for what they use.
- **Cost Model-based Incentives:** In this model, the price of data access is determined by the cost incurred in producing, maintaining, and securing data plus a profit margin. This approach ensures the data providers are compensated fairly.
- **Competition Model-based Incentives:** This involves pricing data based on market analysis and competitor pricing, which can foster a competitive and dynamic pricing environment. This model helps maintain relevance and affordability while enabling providers to adjust to market trends.

- Other Monetary Mechanisms: A range of fee structure can be employed to develop adaptable monetary incentives that fit different data sharing states. The following are some examples of monetary mechanisms:
 - Transaction-based Fees: In this structure, a fee is charged for each data exchange promoting economical use of data.
 - Subscription Fees: Monthly or annual subscriptions allow continuous data access, providing reliable revenue for data providers while ensuring consistent data flow for the data recipients.
 - Flat Fees: One-time payments to gain full access to datasets, ideal for static datasets such as infrastructure maps or schedules that do not change.
 - Data Per Record Fee: These charge fees according to the number of records accessed; this may be especially useful for datasets where each entry is quite granular (for example, traffic incident reports).
 - Fee depending upon usage — based on the amount of data being used (high-frequency means you pay high; low-frequency means you pay less).

Non-monetary Incentive Models

- Alignment with Regulatory Requirements and Policy Support
 - Engaging with data space positions organizations to align with current and future regulatory requirements such as those pertaining to data-sharing, sustainability, transparency & comprehensibility which may mitigate compliance burden to some degree through government alignment in support of these initiatives.
 - Compliance with Data-Sharing Standards and Regulations: The data space establishes an organized structure of compliance, serving as a guide for participants to follow through on GDPR and other regulations easily.
 - Compliance with National and EU Sustainability objectives: All participants are in line with the provisions of Ireland's Climate Action Plan, as well as the mobility and sustainability aim of the European Union, which may bolster regulatory assistance or future funding opportunities.
- Access to a Collaborative Innovation Ecosystem
 - Participation in the data space promotes collaboration with different players in the process, e.g. technology suppliers, local authorities, transportation operators and research institutions. This ecosystem is the perfect playground for co-creating solutions, testing ideas and learning from each other.
 - *Innovation labs and pilot programs*: The data space could enable collaborative innovation labs/pilot programs, allowing participants to work together on testing new real-world innovations such as autonomous shuttles, demand-responsive transport or smart parking.
 - *Synergies across industries*: Access to data from other sectors such as energy (for EVs), health (for active travel) and urban planning create cross-industry innovation opportunities, allowing actors to develop integrated solutions addressing multiple domains of urban life.
- Opportunity to develop innovative data driven solutions
 - Given access to a broader and higher quality data, participants (e.g., MaaS operators) will be able to develop innovative solutions that will enable to gain insights into the

trends, qualities of how people use various services today as well as gaps in these services which help them to quickly develop innovative new solutions leveraging their raw discovery inputs around data.

- **Insights into User Behaviour:** Data can also provide information about trips taken and offered, operational time, and modal preferences of users thus helping the participant in understanding dynamic user demands for providing value (Eco-routing, congestion management, or integrated multi-modal services).
- **Analytics and AI Opportunities:** The availability of aggregated data enables participants to utilize predictive analytics and AI for modelling demand, optimizing resources, forecasting market trends, and supporting innovative service planning and deployment strategies.

4.2.1.2 Use Case Development

Mobility use cases demonstrate the intrinsic value of data spaces in this sector. These are particularly relevant in scenarios in Irish mobility sector where two or more participants e.g., a MaaS operator and government organizations such as SEAI or TII exchange data with the intent of creating business, social, or environmental benefits. Such use cases serve as pivotal elements of the data space, extending its functionality and enhancing its overall value.

As prescribed by DSSC, use cases in data spaces are developed in two iterative steps: identifying and monitoring use cases scenario and refining the use cases. Table 3 shows the key functions of these two steps.

Table 3: Elements of use case development

Elements of Use Case Development	Description
Identifying and Monitoring Use Case Scenarios	Generating use case scenarios includes tasks such as watching potential users in action, studying successful implementations on other data spaces and platforms, or finding gaps where there is value to be produced with data sharing. In this way, it leads to the creation of use cases that are both relevant and impactful based on real-world needs.
Refining the use cases	The refinement of use case scenarios relies on structured templates like the Data Cooperation Canvas, Use Case Playbook, or custom-built wrappers. These tools systematically plot out what each use case aims to do, who the players are, how data flows in and out of these scenarios as well as their respective value proposition and go-to-market details. Utilization of such templates allows use case scenarios to become very specific, implementable, and in alignment with high-level strategic objectives.

This project has identified a range of value-driven use cases across various areas, including, but not limited to, multimodal route planning and booking, EV charging network planning, mobility hubs, first-mile and last-mile freight solutions, demand-responsive transit, and infrastructure planning. Section 3 provides an in-depth discussion of use cases in five key areas. The IMDS initiative can further evaluate

these use cases to determine their feasibility and impact, ultimately selecting the most suitable use cases for implementation in the full-scale IMDS.

4.2.1.3 Data Sources

In Deliverable 2, we explored a range of open data sources within Ireland's transport sector, including contributions from the CSO, TII, TFI, RSA, and others. This section takes that analysis further by mapping these data sources to the identified priority areas, illustrating how their diverse use cases can benefit from efficient data sharing.

Table 4 presents a concise yet comprehensive overview of this mapping, showcasing the connections between data sources, their practical applications, and the potential benefits they bring to Ireland's transport ecosystem. It highlights how leveraging these data sources can drive innovation, improve operational efficiency, and contribute to the development of sustainable and effective mobility solutions.

Table 4: The sources relevant to the use cases

Priority Areas	Relevant Data Sources
Mobility as a Service (MaaS)	<i>National Transport Authority</i> : Provides datasets on public transport routes, schedules, and real-time information [13].
	<i>Transport Infrastructure Ireland</i> : Offers data on transport infrastructure, including road networks and traffic volumes [14].
	<i>Central Statistics Office (CSO) Transport Hub</i> : Aggregates transport statistics from various public sector organizations [15].
	<i>Transport for Ireland</i> : Provides APIs and datasets for real-time public transport schedules, route planning, and passenger information [16].
	<i>OpenStreetMap Ireland</i> : Offers open-source geospatial data for mapping transport infrastructure, cycling networks, and mobility hubs [17].
	<i>Irish Rail (Iarnród Éireann)</i> : Data on rail schedules, real-time train locations, and passenger statistics [18].
	<i>Irish MaaS Applications</i> including TFI Live App[19], LUAS App [20], Uber [21], Free Now [22], GoCar [23], NextBusDublin [24], Moovit [25], DublinBikes [26], Bleeperbike [27].
	<i>Smart Dublin Initiative</i> : A repository of smart city projects and datasets focused on traffic, mobility hubs, and sustainable transport solutions [28].
	<i>GeoHive</i> : Provides geospatial datasets on transport networks, land use, and infrastructure planning [29].
	<i>Cycling Ireland</i> : Data on cycling participation rates, infrastructure needs, and cycling events [30].
Electric Vehicle (EV) Ecosystem	<i>Sustainable Energy Authority of Ireland (SEAI)</i> : Provides data on EV adoption rates, charging infrastructure, and energy consumption [31].

	<p><i>ESB Networks</i>: Offers information on the national electricity grid, including EV charging station locations and capacities [32].</p> <p><i>Department of the Environment, Climate and Communications (DECC)</i>: Provides data and policy reports on renewable energy integration, EV adoption, and decarbonization initiatives [33].</p> <p><i>Zap-Map Ireland</i>: Interactive platform showing real-time availability of EV charging points across Ireland [34].</p>
Demand-Responsive Transit (DRT)	<p><i>TFI Local Link</i>: Manages data on rural transport services, including demand-responsive routes and schedules [35].</p> <p><i>NTA Data Portal</i>: Contains datasets related to public transport usage and demand patterns.</p>
First-Mile Last-Mile Freight Solutions	<p><i>CSO Transport Statistics</i>: Includes data on freight transport volumes, modes, and logistics patterns</p> <p><i>Dublin Port Company</i>: Provides information on freight traffic, port operations, and logistics.</p> <p><i>Freight Transport Association Ireland (FTAI)</i>: Insights and data on freight movement, logistics patterns, and challenges in Ireland [36].</p> <p><i>IMDO (Irish Maritime Development Office)</i>: Datasets on maritime freight, port operations, and intermodal connectivity [37].</p>
Mobility Hubs	<p><i>Dublin City Council Open Data Portal</i>: Provides datasets on urban planning, transport facilities, and land use.</p> <p><i>NTA's Greater Dublin Area Cycle Network Plan</i>: Offers data on existing and planned cycling infrastructure.</p>
Infrastructure Planning	<p><i>TII Data Portal</i>: Offers comprehensive datasets on road infrastructure, traffic counts, and project planning.</p> <p><i>CSO Transport Hub</i>: Aggregates data from multiple sources to support infrastructure planning [38].</p>

4.2.1.4 Data Product

Data products serve as fundamental units of data sharing, incorporating resources (such as data and/or data services) alongside metadata that delineates licensing terms, resource attributes, and other vital details in a machine-readable format. These data products are essential for fostering seamless data exchange, enabling participants to discover and utilise data in a self-service manner.

Data Product Management and Maintenance

Data product owners within Ireland's mobility ecosystem are responsible for the creation, management, maintenance, and retirement of data products. They consolidate diverse mobility data from a variety of sources, including the National Transport Authority (NTA), Irish Open Data Portals, Transport for Ireland (TFI), transport operators, IoT sensors, traffic systems, and user-generated application data. This data is then structured into accessible formats while adhering to the conditions established by data rights holders.

- Data product governance is a key responsibility for the data product owner, ensuring adherence to GDPR and EU data sovereignty principles. The data control, permissions, and privacy

protections are managed by owners—not mediated by a third party who profits while losing trust with everyone involved. To enable interoperability, data product owners need to make metadata rich and consistent, at a minimum covering the following aspects: data type clarity, meaning of information, units of measurement used, quality score assigned by provider sources, or provenance of data. Security, rights, and usage information need to be lamped up in thorough documentation, and all the data must be validated for completeness and accuracy.

- These data products are published in a catalogue by their providers and play roles as data transaction participants during different lifecycle phases, such as negotiation and execution. When contracts are established, providers must abide by data product contracts that enforce usage terms.
- Data product consumers find and use data products based on their individual needs. The licensing terms are laid out in the data product contracts, which they need to review and agree to before getting access to the data. Such a self-service method facilitates collaboration and drives innovation in the IMDS.

Accountabilities and Roles in Data Product Management

- *Data Product Owners:* Owners in Ireland's mobility ecosystem are responsible for developing, managing, maintaining, and revoking data products. They aggregate transport data from diverse sources such as the National Transport Authority (NTA), Irish Open Data Portals, Transport for Ireland (TFI), IoT sensors, traffic systems, and crowdsourced app-generated data. This data is packaged in formats ready for consumption while adhering to the terms and conditions set by data rights holders. Governance of data products is a core responsibility of the data product owner, ensuring compliance with GDPR and EU data sovereignty principles. Data owners oversee control, permissions, and privacy protection to maintain trust among participants. They must provide consistent and comprehensive metadata, detailing type, meaning, units, quality, sources, and history to support interoperability. Security, rights, and usage details must also be documented, and all data validated for accuracy and completeness.
- *Data Product Providers:* Participants in the IMDS publish these data products in a shared catalogue and engage in all stages of data transactions, from negotiation to execution. Once agreements are reached, providers adhere to data product contracts to ensure compliance with usage terms.
- *Data Product Consumers:* Consumers discover and utilise data products according to their needs. They review and agree to licence terms specified in the data product contracts before accessing the data. This self-service model streamlines collaboration and encourages innovation within the IMDS.

Value of Data Products in the IMDS

- Data products are central to enhancing the interoperability of mobility data across Ireland, enabling stakeholders to make informed decisions. By ensuring compliance with GDPR and EU data sovereignty standards, the IMDS facilitates secure and transparent data exchange. This trust fosters collaboration among public agencies, private operators, and other stakeholders, driving innovation and improving Ireland's mobility solutions. High-quality, well-documented data products also enhance operational efficiency, support regulatory compliance, and enable sustainable transportation planning, reinforcing the IMDS's strategic objectives.

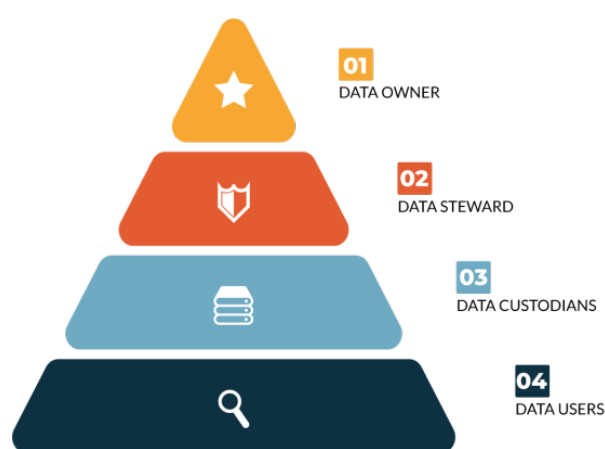
4.2.1.5 Data Ownership

Data ownership is an essential element of effective governance within data spaces. It establishes unambiguous accountability and responsibility for data, ensuring that all participants clearly understand their roles in managing, accessing, and protecting data within the ecosystem. A well-defined approach to data ownership fosters transparency, trust, and adherence to legal and ethical standards.

Data Ownership Model

The data ownership model (See Figure 3 sourced from [39]) for the data space must address the specific requirements of managing mobility-related data, ensuring all participants clearly understand their roles and responsibilities.

Figure 3: Data ownership model



The model should incorporate the following elements:

- Data Owners
 - Role: Accountable for the data within their specific domain (e.g., public transport operators, private mobility providers, or government agencies).
 - Responsibilities: Ensure the accuracy, reliability, and security of the data under their ownership.
 - Focus: Define data policies, establish data standards, and oversee compliance with the IMDS Trust Framework.
- Data Stewards
 - Role: Represent data owners and manage the day-to-day operational aspects of the data.
 - Responsibilities: Maintain data accuracy, consistency, and security while supporting governance processes.
 - Focus: Implement policies, monitor data quality, and manage updates to datasets, particularly for dynamic data like real-time traffic or transit schedules.
- Data Custodians
 - Role: Handle the technical management and protection of the data.
 - Responsibilities: Store, back up, restore, and secure data, ensuring it is accessible to authorised users.

- Focus: Manage the technical infrastructure, especially for high-volume mobility data such as GPS coordinates or IoT sensor outputs.
- Data Users
 - Role: Individuals or systems accessing mobility data for specific purposes, such as service optimisation, route planning, or analytics.
 - Responsibilities: Use data responsibly and in compliance with governance policies.
 - Focus: Follow access controls and respect the data usage terms defined by the data space.

Responsibilities of Data Owners/Data Ownership Protocol

Data owners play a pivotal role in the data space ecosystem, particularly given the dynamic nature of mobility data. Their key responsibilities include:

- Define Data Management Policies
 - Data owners should define the policies for managing the data. The policies primarily include the how the data should be managed within the data space.
- Data Quality Management
 - Ensure datasets are accurate, complete, and consistent, such as real-time updates for GPS data or vehicle telemetry free from errors.
 - Establish metrics and standards for mobility data quality and monitor performance actively.

4.2.2 Governance

This section introduces the **governance building blocks** of the IMDS, detailing their significance. It provides a comprehensive explanation of the processes and strategies required for the effective implementation of these building blocks, ensuring that the governance framework supports transparency, accountability, and collaboration among stakeholders while aligning with national and EU regulatory requirements.

4.2.2.1 Governance Structure

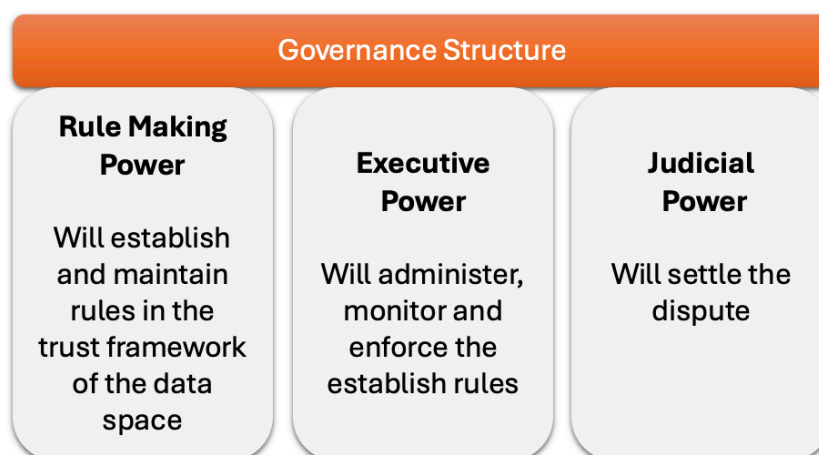
The governance framework of a data space is an internal framework of rules and policies that guide all participants in the data space. Such a framework guarantees consistency in practices, compliance and shared accountability while creating a trustworthy and secure grounds for data sharing and collaboration.

The governance authority not only creates and maintains these internal rules it also implements them into an active operation. Such governance and authority underpin the governance model wherein explicitly defined roles and associated responsibilities and obligations govern all parties when tackling needs, challenges or evolving requirements to retain the value, integrity and security of a data space.

Governance is implemented in a data space as living—it changes with the maturity and size of the data space over time. The same applies to data space: as it emerges and matures, governance mechanisms and policies can be improved to meet emerging needs, serve a larger number of participants and allow for more complex data-sharing. This fosters responsiveness to changing requirements and allows the data space to grow sustainably by ensuring trust, security, and adherence to rules. The Centre of Excellence for Data Sharing and Cloud [40] developed a data sharing governance structure shown in

Figure 3. The governance structure consists of rule-making power, executive power and judicial power (see Figure 4). The Irish mobility data space may adopt this governance structure.

Figure 4: The governance structure



Rule Making Power

The Rule-Making Power of a data space oversees defining and maintaining Trust Framework agreements to enable secure and trusted collaboration amongst the participants. They establish the rules, standards and protocols that guide behaviour in the data space and create a foundation for aligning interests and trust.

For the Trust Framework agreements to be able to continue to serve its purpose, it must be sustained and periodically adjusted in line with change in participant needs, expectations and requirements. By proactively approaching these issues, framework remains applicable even with ongoing challenges threat, technology developments and changes in regulation.

One of the critical components of functionality to support this dynamic process is the agreement management for Trust Frameworks. It allows the agreements to be reviewed, revised, and communicated smoothly, allowing for future changes in the data space to happen easily while upholding trust and collaboration principles that originally laid the foundation of the data space.

Executive Power

The Executive Power is responsible for implementing, observing and executing the Trust Framework contracts; it guarantees that all organizational functions exist to operate and manage the Trust Framework. The steward ensures the daily operation and adherence to regulations of all participants in accordance with the rules and standards adopted in that data space, so this role is a pillar for the operational integrity of a data space. *Several functionalities have been identified which will be detailed in the Trust including* Framework for cross-Domain Data Sharing, Enforcement body, Monitoring body, Marketing, Service Registry management, Trust Framework Participant enrolment, facilitating test tooling, Change and release management, and Knowledge management. These functionalities constitute an important part of Executive Power and embody accountability, scalability and efficiency for data space. The Executive Power safeguards the sustainability and success of the Trust Framework as an instrument for secure and reliable data collaboration by keeping on providing strong oversight and support mechanisms.

Judicial Power

The Judicial Power in the context of data space governance is a power that resolves disputes that might arise between participants. It handles conflict resolution in a trusted way and helps to ensure the integrity of the data space. A key element of the Judicial Power is the role of Dispute Case Manager who oversee and manages the resolution process. This includes:

- **Dispute Assessment:** Assessing the nature and scope of disputes to determine their validity and complexity.
- **Mediation and Arbitration:** Helping to bring together opposing sides of a dispute in order to obtain agreement or providing neutral arbitration if needed.
- **Rule Consistency:** Dispute resolution processes shall be consistent with the agreements and governance policies embodied in the Trust Framework.
- **Case Documentation and Reporting:** Keeping records and reports of past disputes with possible consequences to keep transparency and assist in gathering knowledge for future governance reforms.

Judicial Power also plays a fundamental role in tightening accountability and fairness, which are indeed the principles underpinning any data space and enabling its assimilation between its subjects.

4.2.2.2 Participation Management

Among data space governance elements, Participation Management addresses the processes that ensure participants make use of the data space in a regulated manner. This covers everything from how participants will be identified and onboarded, offboarded, and the governance rules related to data transactions, as well as options for enablement and intermediation services. Everyone who enters the data space to participate in a data transaction, either directly — as parties transacting with each other; indirectly — by offering services to facilitate such transactions; or as holders of rights in relevant data is considered a party. These users are likely to be incentivised into a data space for different reasons, typically linked to unique business goals but also specific requirements and expectations around usage.

Roles of Participants

- **Data Providers** → Entities that create and provide information to the data space. They provide datasets that other users in the data space can use.
- **Data Consumers:** Entities who make use of the data in the data space — examples include organisations or individuals who perform analysis, make decisions, build products and more. This is where the actual data transactions are being carried out.
- **Data Intermediaries and Operators Role:** These are entities that facilitate the exchange of data between providers and consumers by providing enablement and intermediation services. While not directly involved in data transactions, they are critical stakeholders of the data space. Consequently, participation management must make sure that the intermediaries and operators conform to interoperability standards, resulting in easy data exchange.

Participation management must address both data provider and data consumer aspects such as common administration of permissions, enforcement of data quality requirements, and the capabilities to track and audit data usage.

Onboarding and Governance

Automated onboarding processes are the backbone of a data space. Such processes ensure quick onboarding, compliance with necessary technical and regulatory standards, while reducing operational inefficiencies and data misuse risks. Onboarding helps create a robust ecosystem for the data space by fostering trust and collaboration among participants.

The Data Space Governance Authority could address this by providing minimum requirements for participation. These include defining General Terms and Conditions (GTC) that outline rules for joining the data space, ensuring participants understand their roles, responsibilities, and compliance obligations. Such terms often include conditional admission, technical standards, data protection policies, identity verification methods, and attestation issuance (first, second, or third-party) methods.

Balancing Rules and Accessibility

The breadth and intricacy of the rules around participation in a data space are commensurate with its mission. Revamping the supply and demand sides via stricter rules could improve data transaction quality and security but might also deter potential data providers. As a result, participation rules must be carefully engaged (either individually or en masse) to maximise data space goals and minimise friction. Data spaces can implement other internal rules and policies if necessary, but these should focus on streamlining the participation process and enhancing the overall functionality of the data space.

4.2.2.3 Dispute Management

The governance authority of Irish Mobility data Space should prioritise the creation of a robust dispute resolution mechanism as an integral part of its governance framework. This mechanism would act as a neutral platform to address conflicts among stakeholders, ensuring that disputes are resolved impartially, transparently, and in a timely manner. While the IMDS will operate under rules and regulations established in accordance with legal procedures, the addition of an expert arbitration process would provide an alternative to traditional legal actions, offering a streamlined and specialised approach to resolving conflicts.

The dispute resolution mechanism should include expert arbitration bodies composed of neutral specialists with in-depth knowledge of mobility data spaces, governance structures, and standards. These bodies would mediate conflicts, providing technical and legal expertise to ensure fair outcomes. Such a mechanism would not preclude stakeholders from seeking redress in national courts but would serve as an efficient and collaborative alternative, reducing the time and costs associated with formal legal proceedings.

The scope of this mechanism would extend to various types of conflicts, including disputes regarding compliance with data-sharing agreements, governance practices, and technical standards. It would be particularly critical in addressing disagreements between individual mobility data space instances, the central IMDS, or even conflicts among the individual instances themselves. A clear mediation process would ensure these disagreements are resolved constructively, preserving the integrity of the IMDS and reinforcing its role as a trusted and unified data-sharing ecosystem.

The benefits of such a mechanism include its ability to facilitate efficient conflict resolution, reducing operational disruptions and fostering a cooperative environment among stakeholders. It would also

enhance the IMDS's credibility by ensuring fairness and transparency in handling disputes, thereby strengthening stakeholder confidence in the system. Furthermore, the mechanism would play a vital role in promoting standardisation by resolving disagreements over standards and governance in a consistent and equitable manner.

By integrating this dispute resolution mechanism, the IMDS would establish itself as a resilient and sustainable platform capable of maintaining trust and collaboration while addressing the evolving needs of its stakeholders. This approach ensures that conflicts are managed constructively, fostering a cohesive and effective mobility data ecosystem.

4.2.3 Legal

This section outlines the **legal building blocks** of the IMDS. It provides detailed insights into how these legal components will be implemented in the production version of the IMDS, addressing critical aspects such as data ownership, usage rights, privacy compliance, contractual agreements, and alignment with national and EU regulations, including GDPR [45] and the Data Governance Act [46].

4.2.3.1 Regulatory Compliance

Regulatory compliance is a fundamental pillar of the IMDS, ensuring that all its operations adhere to the relevant legal frameworks at both national and EU levels. This encompasses a wide range of activities, including interpreting and implementing regulatory requirements, embedding compliance into every aspect of the data space, and facilitating lawful data sharing and collaboration among participants.

Given the complexity and diversity of data handled within the IMDS, compliance spans personal data protection, intellectual property rights, trade secret safeguards, and non-personal data regulations. The governance authority plays a pivotal role in overseeing these efforts, identifying relevant laws, and establishing mechanisms to ensure full compliance.

Key Areas of Regulatory Compliance

- **Personal Data:** Handling personal data requires strict adherence to strong privacy regulations to protect individuals' rights. Key instruments include:
 - **General Data Protection Regulation (GDPR) (EU Level):** A binding framework for the protection of personal data across the EU, ensuring lawful processing and safeguarding individual privacy.
 - **Data Protection Act 2018 [47] (National Level):** Ireland's implementation of GDPR and related legislation, providing specific provisions for privacy rights and responsibilities within the country.
 - **Law Enforcement Directive (Directive (EU) 2016/680) [48] (EU Level):** Governs the processing of personal data for law enforcement purposes and is transposed into Irish law via the Data Protection Act 2018.
 - **e-Privacy Directives (EU Level) [49]:** Regulate electronic communications, addressing data privacy in online communications such as email and SMS.
- **Trade Secrets and Intellectual Property Rights:** IP and trade secret protections are critical tools for protecting innovation and proprietary information. Key instruments include:
 - **Copyright and Related Rights Act 2000 [50] (Ireland):** Asserts the rights of authors in relation to intellectual property, including moral and integrity rights.

- InfoSoc Directive (2001/29/EC) [51] (EU Level): Unifies copyright laws across EU member states while enacting elements of the WIPO Copyright Treaty.
- Sui Generis Database Right (EU Database Directive 96/9/EC) [52] (EU Level): Protects non-copyrightable databases that involve substantial investment in their creation.
- Trade Secrets Directive (Directive (EU) 2016/943) [53] (EU Level): Protects confidential business information and know-how from misappropriation and unauthorised disclosure.
- Non-Personal Data: Although non-personal data is not directly tied to individuals, its secure and efficient use demands regulatory oversight. Key legislative instruments addressing this include:
 - Data Act [54] (EU Level): This act fosters the sharing and utilization of non-personal data across the EU, driving innovation and enabling data-driven solutions.
 - Open Data Directive (Directive 2003/98/EC) [55] (EU Level): Aims to promote transparency and accessibility by encouraging the re-use of information from the public sector.
 - Data Governance Act (EU Level): Establishes a secure framework for sharing sensitive data between public and private entities.
 - Digital Markets Act (DMA) [56] (EU Level): Ensures fairness and competition within the digital economy by regulating major digital platforms.
 - Digital Services Act (DSA) [57] (EU Level): Targets issues such as illegal content, disinformation, and advertising transparency on online platforms.
 - Data Sharing and Governance Act 2019 [58] (National Level - Ireland): Oversees data-sharing practices between public bodies, enhancing the management and accessibility of public service information.

Implementation Strategies for Regulatory Compliance

To ensure full adherence to regulations, the IMDS governance authority should carry out the following actions:

- Regulatory Monitoring: Regularly track changes in Irish and EU regulatory frameworks to identify relevant rules and ensure the data space evolves alongside legal developments.
- Embedding Compliance in the Trust Framework: Integrate detailed compliance requirements into Trust Framework agreements to guide participants in lawful data-sharing, processing, and management practices.
- Participant Monitoring and Enforcement: Actively oversee participant activities within the IMDS to verify regulatory compliance. Establish mechanisms for addressing non-compliance, including penalties or corrective actions.
- Capacity Building and Support: Provide tools and resources like standardized compliance checklists, test environments, and training to help participants understand and meet regulatory requirements.
- Cross-Domain Coordination: Facilitate smooth integration of data services across sectors while maintaining compliance with sector-specific regulations and ensuring interoperability between data-sharing ecosystems.

4.2.3.2 Contractual Framework

The Governance Authority and the participants of Irish Mobility Data Initiative must establish a contractual framework. The contractual framework consists of legally binding agreements establishing the relationships between data space participants and transaction participants. This framework falls into

two types of agreements, namely data space agreements and data transaction agreements, as defined in the DSSC blueprint. The two differentiating components between these agreement types are: (1) the event that makes agreements binding (e.g., joining a data space or executing a specific transaction), and (2) the parties covered by the agreement (all data space participants versus only those participating in a specific transaction).

Data Space Agreement

Data space agreements provide an overarching and layered contractual framework for involvement in a data space or the provision of services aligned with it. These agreements not only define the overall terms and conditions of participation, but also provide the legal basis for the existence and functionality of data space. They delineate the boundaries and governance of the data space, ensuring conformity to regulatory frameworks with standardized components including pre-defined clauses and licensing terms. Data space agreements provide the structural and operational foundation for the data space through the implementation of the governance framework.

Data Transaction Agreement

These are the agreements to exchange data between certain organizations in that data space. These accords are done on a bilateral basis along with the technological implementations needed to make data sharing happen. These agreements are only binding for the transaction participants participating in a particular data transaction when one of the data space participants conducts such a specific data transaction. More specifically, data transaction agreements often come in the form of data product contracts that provide a legal framework for governing the data transfer. The contracts serve as a legitimate, enforceable legal framework upon which all involved parties are bound in the cases of disputes between actors.

4.2.4 Technical Architecture and Functional Architecture

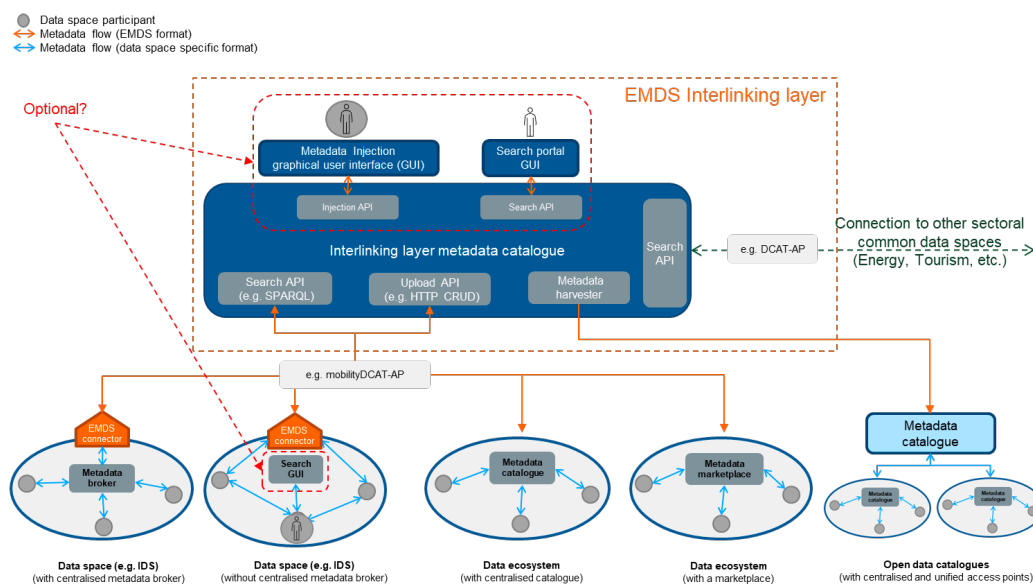
The IMDS is designed in such a way as to facilitate the secure and interoperable exchange of mobility data among various stakeholders, such as government agencies, public and private transport operators, and third-party developers. The key functional components of this data space encompass data collection and sharing protocols, interoperability standards, a comprehensive interaction model, and a user-centric UX (User Experience) design. This section outlines key functional elements that facilitate data sharing, interoperability, and user interaction within a MDS environment, aligned with best practices from DSSC, EMDS, and DeployEMDS.

4.2.4.1 Technical Architecture

This section elaborates on the various system architecture options identified for designing and implementing the interlinking layer. The analysis is based on data collected from multiple sources, including interviews, analysis of reference architectures, and insights from workshops. Understanding the strengths and weaknesses of different architecture options is crucial for making informed decisions that align with the interlinking layer's requirements, constraints, and future scalability needs. The characteristics, benefits, and potential drawbacks of each architecture type will be examined, providing a comprehensive overview to guide our architectural choices.

In general, the system architecture forms the backbone of the interlinking layer, dictating how components interact, how data flows through the system, and how the system scales and adapts to changing demands. deployEMDS conducted an evaluation with different architectural options and recommended the architectural style shown in Figure 5.

Figure 5: Solution architecture for centralised scenario



In this architecture, all metadata processing, storage, and management tasks are handled by a **centralised cloud infrastructure**, which acts as the core component of the system. This infrastructure manages requests from multiple client nodes, enabling them to interact directly with the interlinking layer for various computing needs, including the publication, maintenance, and querying of metadata. The centralised model provides flexible options for publishing and querying metadata. Depending on the characteristics of data providers and the data ecosystems they belong to, metadata can either be **pushed** directly into the interlinking layer or **pulled** into its storage.

For the **push option**, metadata is uploaded using the **Upload API module** provided by the interlinking layer. In this case, data providers manually execute an upload request and include their metadata in the body of the request. For the **pull option**, metadata extraction from data ecosystems or data spaces can be performed in multiple ways:

- If data providers are part of data spaces that follow the specifications of major European data space initiatives (e.g., **IDS** or **Gaia-X**), a specialised **EMDS Connector** can be utilised. The EMDS Connector fetches metadata either directly from the data provider's connector or from a data space-specific metadata repository or broker. The collected metadata is then transmitted to the interlinking layer for storage.
- Additionally, metadata can be harvested using **NAP-compliant catalogues**, which retrieve content directly from metadata catalogues maintained by various local **National Access Points (NAPs)**.

This flexible approach ensures compatibility with diverse data ecosystems and supports seamless integration with existing European data space initiatives.

4.2.4.2 Data Modelling and Interoperability Standards

Data models are essential to guarantee the coherent interpretation of data when shared within a data space. These models carry metadata that conveys semantic information, enabling participants to understand the data they are consuming. Data models are especially relevant for interactions between two participants in a data space who wish to exchange data. By adopting a common data model, participants can achieve semantic interoperability, facilitating seamless data exchange across the data space ecosystem.

To achieve semantic interoperability, data space participants must describe their data (or any products offered) in accordance with a harmonised data model as defined by the proprietary governance framework of the data space. These standardized data models are provided by data model providers under the supervision of the data space governance authority. When these models are published, they are stored in a vocabulary service — essentially a repository used for finding and referencing data models throughout the data space. During the actual data exchange, all participants consult their respective vocabulary service and refer to the same data model.

The data model process identifies four abstraction layers that contain metadata about the shared data:

- Vocabulary: Specifies the low-level concepts and relationships, defined as terms and definitions within or across domains. This is usually implemented using meta-standards like the Simple Knowledge Organization System (SKOS) [59], which is widely adopted for publishing and linking taxonomies and classification schemes.
- Ontology: Models information objects and their relationships to capture knowledge within and across domains. This is frequently formalised using open metamodel standards such as the Web Ontology Language (OWL) [60], Resource Description Framework (RDF) [61], or Unified Modelling Language (UML) [62].
- Application Profile: Provides targeted data modelling for applications addressing specific use cases. Beyond shared semantics, it imposes additional constraints like cardinalities or specific code lists. It acts as a blueprint for analysts and developers, offering clear guidance for implementing the data model in real-world applications.
- Data Schema: Represents an application profile in a particular technology. It includes detailed syntax, structure, data types, and constraints essential for data exchange. By specifying the exact format for data exchange, it ensures technical interoperability.

The IMDS relies on comprehensive interoperability standards to enable seamless, cross-platform data exchange, aligning with EU-wide mobility goals and ensuring technical and semantic compatibility across stakeholders. Key interoperability standards include:

1. DCAT-AP [63]: Facilitates standardized data cataloguing across EU datasets.
2. Alignment with EU Initiatives: Mobility Data Spaces align with NAPCORE, MaaS Alliance, and the European Mobility Data Space, ensuring synergy with EU-wide mobility solutions.
3. Transport Data Standards: Supports GTFS and GBFS for public transit feeds, and TIDES, TODS, TN-ITS, and NeTEx for harmonized multimodal transport data, promoting unified solutions across different transportation modes.
4. CEN/ISO Standards: Ensures consistent data quality, supporting international compatibility.

The IMDS adopts standard data formats like JSON [69], XML [70], and communication protocols such as RESTful APIs and MQTT [68] to facilitate seamless data sharing across various mobility services. By incorporating DSSC and deployEMDS recommendations, it ensures both technical and semantic interoperability, enabling reliable and consistent data interpretation. This framework supports key applications such as real-time transit planning, integrated ticketing, and multimodal transport solutions, fostering a collaborative and interconnected mobility ecosystem aligned with the EU's digital transformation objectives. Functional requirements focus on enabling multimodal trip planning, first-mile/last-mile integration, smart parking systems, and infrastructure planning. These standards ensure real-time data sharing across different transport modes, allowing users to plan, book, and pay for integrated services while maintaining data privacy, security, and GDPR compliance. Ultimately, the MDS aims to create an efficient, scalable, and user-friendly ecosystem that enhances mobility services and supports data-driven decisions for sustainable transport development.

4.2.4.3 Data Product Offerings Descriptions

In the **Irish Mobility Data Space**, providers utilize **metadata** to describe their organizations, their data product offerings, and the resources composing these offerings. These metadata records, referred to as **Self-Descriptions**, are designed to be comprehensible not only to human data consumers but also to automated machine agents that support data processing and decision-making. This universal comprehensibility is achieved by adhering to established **Semantic Web** and **Linked Data** standards.

- Standards Supporting Self-Descriptions: The Self-Descriptions in the IMDS are built upon internationally recognized standards developed by the World Wide Web Consortium (W3C) [65], including:
 - DCAT (Data Catalogue Vocabulary) [67]: A standard for publishing and managing data catalogues.
 - DCAT-AP (DCAT Application Profile): A European profile of DCAT for cross-border data sharing.
 - Mobility-DCAT-AP [66]: A specialized profile of DCAT-AP tailored for mobility data, enabling consistent representation of datasets, services, and resources relevant to the mobility domain.

These standards not only define schemas to structure the data but also document the meaning of every term within the schema. This documentation is expressed in both **natural language** (for human users) and **machine-actionable logic** (for automated systems). By ensuring dual comprehensibility, these standards facilitate interoperability across diverse stakeholders and systems within the IMDS.

Enabling Interoperability

Self-Descriptions play a pivotal role in enabling **semantic interoperability** within the IMDS. By embedding universally understood semantics into the metadata, they allow data providers and consumers to exchange and interpret information consistently, regardless of the specific systems or platforms in use. For instance:

- Data providers can use Self-Descriptions to define the attributes of their mobility datasets, such as real-time traffic updates, vehicle locations, or environmental metrics.

- Data consumers, including Mobility as a Service platforms or public transport authorities, can rely on these Self-Descriptions to identify, interpret, and integrate data from multiple providers seamlessly.

Moreover, the machine-readable nature of Self-Descriptions allows automated agents to process and reason about the data effectively, supporting advanced applications such as AI-powered route planning, dynamic demand forecasting, and predictive maintenance of mobility infrastructure.

4.2.4.4 *Publication and Discovery*

Publication and Discovery serves to publish and discover data product offerings in a data space. Data product offerings descriptions (see Section 4.2.4.3) are created and maintained by their data providers. These descriptions are stored in a catalogue, and it is the data provider's responsibility to manage them throughout their lifecycle—from publication to being retired or removed from availability.

Once data product offerings are published, data consumers can query the catalogue to find and evaluate existing offerings, identifying those that best suit their needs. A robust Data Product Discovery mechanism ensures that data products are Findable, thus adhering to the FAIR principle. To achieve this, the Data Product Discovery mechanism must exhibit specific traits:

- Automated connectivity: Enables services to connect without requiring manual intervention.
- Informed decision-making: Provides data service consumers with all necessary information to decide whether to use a specific data service.
- Clear communication: Facilitates communication between data product providers and consumers through a standardized metadata framework.

Data Catalogue

The Data Catalogue, a core component of Data Product Discovery, is an organised repository of metadata about available data products. Similar to a "telephone directory," the catalogue contains all relevant metadata needed to discover and select offerings. Data space participants can design and maintain catalogues in compliance with the Data Space Agreement and act as Data Service Providers. The catalogue manages consumer queries, enabling them to search for relevant data products and providing appropriate responses based on their queries.

Data catalogues can be implemented in several ways based on the data space governance framework. Common types include:

- Decentralized Catalogue
 - Each participant in the data space maintains its own catalogue within its participant agent.
 - Data consumers must query each provider's catalogue individually to discover offerings.
 - A **data space registry** can be used to address this fragmentation by acting as a directory of data space participants and their respective catalogue endpoints.
- Centralized Catalogue
 - A single, central catalogue aggregates all publicly available data product offerings across the data space.

- The centralized catalogue can be made accessible to external actors (e.g., third-party data consumers) under specific conditions, promoting wider visibility of offerings and attracting potential participants.
- Centralization simplifies discovery but requires robust governance and infrastructure, as outlined in frameworks such as **IDS-RAM 4.0** (International Data Spaces Reference Architecture Model) [42].
- Local Catalogue
 - A catalogue maintained by a data provider, with restricted visibility for specific groups of participants.
 - The data provider can limit the discovery of certain offerings or entire catalogues to selected participants, ensuring privacy and control.
 - This approach prevents unauthorized agents from scraping metadata or accessing restricted offerings.

Governance Consideration

The governance framework of the data space should define the most suitable catalogue approach, considering factors such as scalability, accessibility, data sovereignty, and the use case requirements:

- A *centralized catalogue* is beneficial for enhancing discoverability and fostering collaboration but requires centralized coordination and trust in the managing entity.
- A *point-to-point or decentralized catalogue* emphasizes data sovereignty and privacy, requiring consumers to establish direct connections with providers.
- A *local catalogue* provides high granularity of control for data providers, ensuring offerings are visible only to specific participants or groups.

Governance frameworks in data spaces can regulate access, interoperability, and data sovereignty by selecting an appropriate catalogue approach—decentralised, centralised, or local—to effectively meet the individual requirements of participants and use cases.

4.2.4.5 Data Exchange

Data exchange requirements within a data space must be defined based on the specific data transfer characteristics of the intended use cases. These characteristics directly determine how data exchange is implemented. While APIs are effective for transferring small data volumes, they become impractical for larger datasets, which typically require alternative protocols such as FTP servers. To address the diverse and evolving demands of dynamic data-sharing use cases, a forward-looking Trust Framework must incorporate provisions to accommodate a wide range of identified data transfer characteristics. The implementation of data exchange within a data space is fundamentally tied to the Data Plane, which is inherently interconnected with the Control Plane. These two planes, forming the foundation of the Data Spaces Protocol, fulfil distinct yet interrelated functions:

- The **Control Plane** facilitates generic processes and protocols, such as the Catalogue Protocol and the Contract Negotiation Protocol. It is responsible for managing critical aspects such as the establishment of participant identities, enforcement of access policies, and negotiation of data-sharing agreements.

- The Data Plane, in contrast, is domain-specific and directly handles the transmission and access of data between participants. It focuses on the practical realization of data exchange, ensuring that the operational requirements of use cases are met.

When implementing data exchange mechanisms, several key considerations must be addressed for the Data Plane to ensure its effectiveness and alignment with the overarching objectives of the data space:

- Purpose-driven protocols: The selected protocol should correspond to the specific objectives of the data exchange, such as facilitating data sharing or enabling data access, thereby ensuring its suitability for the intended use cases.
- Linkage to data models: The protocol must support the relevant data models associated with the use cases, ensuring both semantic and technical interoperability across participants and systems.
- Integration with the Control Plane: The data exchange protocol must integrate seamlessly with the Control Plane to enable robust enforcement of identification, authentication, and access control policies, ensuring secure and regulated data interactions.

Selecting an appropriate transmission protocol is a critical component in the implementation of the Data Plane. This selection process, detailed in the Transmission Protocol Section of the Data Spaces Protocol, must align with the specific requirements of the data-sharing use cases while adhering to the governance framework of the data space.

Key Considerations for Choosing a Transmission Protocol

- Purpose Alignment: The protocol should cater to the intended purpose of the data exchange, such as batch transfers for large datasets or real-time streaming for dynamic and time-sensitive applications.
- Compatibility with Data Models: It must integrate seamlessly with the semantic and technical data models of the data space, ensuring interoperability and consistency across stakeholders.
- Secure Integration with the Control Plane: The chosen protocol must enable robust integration with the Control Plane to facilitate secure identity verification, enforce access controls, and ensure adherence to established governance policies.
- Examples of Transmission Protocols
 - API-based Protocols: These are ideal for exchanging small amounts of data or enabling real-time access in scenarios requiring low latency and frequent interactions.
 - File Transfer Protocols (e.g., FTP/SFTP): Designed to handle the transfer of large datasets efficiently, these protocols are suitable for scenarios where bulk data exchange is required.
 - Streaming Protocols (e.g., MQTT): Well-suited for continuous or event-driven data exchanges, these protocols support real-time, high-throughput applications where dynamic data is essential.

Documentations and Governance

The selection and implementation of transmission protocols must be thoroughly documented within the Rulebook of the data space. This documentation serves as a critical resource, providing participants with detailed technical specifications to ensure consistency, transparency, and compliance with the governance framework of the data space. By establishing clear guidelines, the Rulebook supports the

seamless operation and mutual understanding among stakeholders, fostering trust and accountability within the data space ecosystem.

4.2.4.6 Data Provenance and Traceability

Provenance and traceability are essential for building trust, ensuring compliance, and maintaining transparency within the IMDS. By leveraging existing standards and guidelines, rather than creating new frameworks, the IMDS can efficiently meet legal, regulatory, and operational requirements. Provenance and traceability help stakeholders understand the origin, handling, and usage of data, supporting secure and ethical data sharing across the mobility ecosystem.

Types of Provenance and Traceability

- Provenance Tracking (Backward-Looking)
 - Enables data consumers to verify the origin and processing history of data.
Examples:
 - Ownership: Establishing proof of land ownership through cadastral records.
 - Custody: Documenting possession via rental agreements.
 - Location: Authenticating geographic origin, such as Gouda cheese being produced in Gouda.
- Traceability Tracking (Forward-Looking)
 - Allows data providers to understand the usage and transformations applied to their data types:
 - Provenance Traceability information directly linked to the origin and handling of data.
 - Non-Provenance Traceability: Broader traceability information used for auditing, billing, and other purposes.

Capabilities for Provenance and Traceability

To implement effective provenance and traceability, the following capabilities must be developed in the IMDS:

- Legal and Regulatory Understanding
 - Identify and interpret relevant laws, regulations, and contractual obligations to define provenance and traceability requirements.
- Domain-Specific Data Models
 - Select or develop data models and vocabularies relevant to mobility data to ensure consistency and interoperability across data providers and consumers.
- Storage and Processing Design
 - Create solutions for storing and processing provenance and traceability data, ensuring scalability and security.
- Authorization and Usage Policies
 - Design robust authorization frameworks and usage policies to control access to provenance and traceability information.
- Validity Criteria and Safeguards
 - Establish safeguards to validate data provenance and traceability, ensuring accuracy and reliability.

Requirements Perspective

- Understanding Provenance and Traceability Types
 - Identify the types of provenance and traceability required, such as ownership, custody, and location, based on regulatory, contractual, and operational needs.
- Domain-Specific Data Models
 - Understand and select appropriate data models tailored to mobility use cases, such as vehicle telemetry or transit schedules.

Implementation Perspective

- Architectural Patterns and Observability
 - Use established architectural patterns and integrate third-party observability services to enhance visibility into data flows and transactions.
- Storage and Security Models
 - Implement secure storage solutions for provenance and traceability data, ensuring compliance with GDPR and other regulations.

Data Models for Provenance and Traceability

- Generic Aspects
 - Use established ontologies like W3C PROV-O (Provenance Ontology) or PAV (Provenance, Authoring, and Versioning).
 - Model data-sharing events using frameworks such as CloudEvents.
- IMDS-Specific Aspects
 - Extend generic models to address specific mobility data needs, such as vehicle ownership records or transit system logs.
 - Document these extensions in the IMDS Rulebook, including legal and functional requirements.

Technical Implementation

- Transfer Process in Control Plane
 - Ensure that provenance and traceability data is recorded during all data transactions on the Data Plane.
 - Both data providers and consumers must store records for future auditing.
- Third-Party Observability Services
 - Use third-party services to maintain an independent record of data provenance and traceability.
 - Combine local storage with external observability for enhanced transparency and auditability.
- Auditing Mechanisms
 - Enable data providers, consumers, and auditors to compare stored records, ensuring consistency and trustworthiness.

4.2.4.7 Data Sovereignty and Trust

Data sovereignty is an essential principle underpinning the management, access and control of data in the Irish Mobility Data Space according to relevant legislation (EU based). This means that personal and

organizational data which could be stored or processed in a country like Ireland is under the laws and regulations of data privacy for that jurisdiction. This follows in importance is the key to building trust, enabling cooperation and alignment with EU priorities when it comes to data protection, security and strategic autonomy.

Understanding Data Sovereignty

Data sovereignty is about giving organisations, governments, and individuals control over their data; it allows a self-determined approach to how data can be collected, stored, shared, and used. This principle is particularly important for the mobility data space, where trust is the bedrock of innovation and participation.

- Core Characteristics of Data Sovereignty
 - Bound by Jurisdiction: Data is governed by the law of the country where it resides or originates.
 - Control & Accountability: Participants take ownership of their data and its utilisation, with the ecosystem being accountable to them.
 - Finding Equilibrium in Protection and Sharing: Data sovereignty aims to find a balance between data protection and the benefits of sharing and cooperation.
- Significance in the Data-Driven Economy
 - Data sovereignty creates a safe and trust-filled environment for participants by ensuring their data is stored securely and transparently. That trust cooperation and ultimately drives innovation, economic growth, and better mobility solutions.

Data Sovereignty in the EU Perspective

In the EU, data sovereignty has always been given special importance and follows from regulations and priorities:

- Data Protection and Privacy
 - GDPR Compliance: The General Data Protection Regulation (GDPR) is a law in the EU that sets guidelines for the collection and processing of personal information, working to ensure citizens have the fundamental rights and freedoms related to their data privacy.
 - Such regulations get enforced by data sovereignty, which provides personal data with strong protection regardless of where it is processed or stored.
- Data Security
 - Under EU jurisdiction over data, strict security measures are required to safeguard sensitive information from breaches or unauthorised access.
 - In the IMDS case, such data could be real-time mobility data, user profiles, and operational analytics.
- Strategic Autonomy
 - Control over a significant part of the data infrastructure in the world is held by companies that, even though they maintain local offices within the EU and employ citizens of EU countries, are still considered non-EU entities by law and can be exposed to external interests. Hence, there are challenges related to dependency on providers who remain outside the jurisdictional scope established in Europe.

- In the case of data sovereignty, this reliance is mitigated: the EU gains more control over its digital infrastructure and achieves a level of strategic autonomy.

Embedding Data Sovereignty into the Irish Mobility Data Space Context

- Policies on Use and Retention of Data
 - As with any data, structuring the Irish Mobility Data Space will have to comply with Irish and EU regulations (GDPR) for it to be used lawfully and ethically.
 - This means data must be stored within EU boundaries to maintain sovereignty and ensure compliance with EU law.
- Control Mechanism
 - Self-Determination: Participants must be able to define the usage policies for their data, approve access to it, and monitor how this data is shared and processed.
- Trust Framework Alignment
 - Full integration of data sovereignty—at a conceptual, legal, and technical level—into the architecture of IMDS will ensure participants trust that their data is protected physically and jurisdictionally and handled in compliance with EU privacy laws.
- Collaboration and Innovation
 - The data space establishes trust by enabling data sovereignty, allowing different parties to share their data, fostering innovative mobility solutions, and promoting knowledge transfers that boost the economy.

4.2.4.8 Information Security

Ensuring robust data security is essential for the IMDS to manage sensitive information affecting public safety, privacy, and organisational security. IMDS's security framework aligns with GDPR and EU regulations to protect data integrity and support stakeholder trust. Key components include:

- Data Encryption
 - Encrypts data at rest and in transit to provide end-to-end network protection.
- Access Control and Authentication
 - Uses role-based access control (RBAC) and multi-factor authentication (MFA) to restrict data access.
 - Implements identity verification standards, such as OpenID and OAuth, to secure access.
- Audit Logs and Continuous Monitoring
 - Maintains detailed audit logs and continuous monitoring systems to trace all mobility data interactions.
 - Ensures compliance and regulatory adherence, promoting accountability.
- Incident Response Protocols
 - Swift response mechanisms are in place to address data breaches or cyber threats.
 - Protocols include real-time alerts, containment procedures, and post-incident analysis to maintain system integrity.
- Data Governance and Privacy
 - Privacy-focused policies, including pseudonymization, minimize personal data exposure where applicable.
 - Pseudonymization is coordinated by Data Protection Officers (DPOs) and technical experts, further enhancing data privacy in public/private sectors.

To enable interoperability and secure identification, IMDS will follow internationally recognized standards and frameworks

- W3C Verifiable Credentials (VC) [71] Data Model for issuing secure digital credentials.
- Decentralized Identifiers (DID) [72] to enable user-controlled, interoperable identifiers.
- eIDAS Regulation [73] Compliance to ensure secure electronic identification, authorization, and authentication.
- ISO/IEC 17000:2020 [74]: Establishes a standardized vocabulary for conformity assessment.
- ETSI 11962 [75]: Defines electronic signatures, trusted lists, and secure digital infrastructures.

IMDS may also employ advanced technologies to ensure security

- Blockchain Integration
 - Leverages blockchain frameworks, such as the European Blockchain Services Infrastructure (EBSI), to enhance verifiable credentials' tamper-resistance and security.
- Data Transmission Security
 - Protects data in transit with SSL/TLS encryption.
 - Utilizes secure channels, such as Virtual Private Networks (VPNs) and Secure File Transfer Protocols (SFTP), to prevent unauthorized access.

These comprehensive security measures create a structured, interoperable, and resilient mobility data space that builds trust among stakeholders and supports sustainable, data-driven transportation solutions across Ireland, well aligned with the EU's digital transformation goals for safer mobility data exchange.

4.2.4.9 Information Management

The IMDS emphasizes structured information management to ensure data remains accurate, accessible, and secure throughout its lifecycle, supporting sustainable transportation initiatives within Ireland and across the EU. These can be achieved through the following steps:

- Data Governance Framework
 - IMDS will be operated under a governance framework defining data ownership, responsibilities, and usage policies.
 - Practices ensure data validation, quality control, and periodic reviews, aligning with EU and Irish regulations for ethical, legal, and responsible data use.
- Metadata Management
 - Metadata organizes and labels data, making it easier to locate and understand.
 - Metadata fields detail the data's origin, collection date, format, and licensing, aiding users in interpreting datasets accurately.
- Data Curation and Quality Assurance
 - Ongoing data curation enhances accuracy and usefulness, while regular quality checks ensure data completeness and relevance.
 - Metadata standards, such as the Data Quality Vocabulary (DQV) [76], and cataloguing tools like CKAN, and EDC, support efficient data discovery and access, promoting high-quality data for decision-making.
- Verifiable Credentials
 - The Open Digital Rights Language (ODRL) [77] specifies digital content policies and rules.

- Using the Resource Description Framework (RDF), ODRL enables interoperable and flexible policy expression for digital content, supporting privacy and usage restrictions with JSON-LD serialization.
- APIs for Verification of Attributes from Trusted Sources
 - Trusted data sources verify legal and organizational attributes, ensuring data accuracy and legitimacy.
 - Examples include APIs for European registration numbers (EORI), VAT (VIES), and Global Legal Entity Identifiers (GLEIF).
- Data Space Registry and Compliance
 - A registry maintains machine-readable rules, trust anchors, and revocation data to ensure ongoing compliance.
 - Standards such as W3C SHACL [78] and JSON Schema validate data structure, format, and semantics, enabling automation, consistency, and interoperability across the data ecosystem.
- Data Lifecycle Management
 - Mobility information is carefully managed from creation through storage, maintenance, and disposal.
 - Lifecycle policies maintain mobility data relevance by archiving or removing outdated information, optimizing resources, and preserving data quality among different departments and authorities.

This comprehensive information management framework in IMDS facilitates effective data-driven decision-making, supporting sustainable mobility initiatives while aligning with EU digital and regulatory goals for secure and ethical data use.

4.2.4.10 Interaction Model

In the IMDS, the Interaction Model outlines how diverse stakeholders such as data providers, consumers, and developers engage with the platform. This model is structured around key functionalities:

- Role-Based Access Control: Stakeholders are assigned roles with specific permissions. For instance, data providers manage data-sharing permissions, while developers gain controlled access to datasets essential for application development.
- Data Marketplace: The IMDS interaction model fosters a marketplace where data can be shared, traded, or monetized. Data providers can offer access for free or under commercial terms, incentivizing data sharing and collaboration.
- User Collaboration and Feedback Loops: Stakeholders contribute feedback to continuously refine data quality, enhance interoperability, and improve user experience. This collaborative approach supports iterative improvements, making the IMDS more responsive to user needs.
- Federated Data Access: Through DeployEMDS, the model supports a federated approach, enabling data providers to manage access and permissions autonomously. This creates a trusted, secure environment conducive to data exchange across platforms.
- User Interfaces and APIs: The model includes APIs for data access and interfaces for visualization, allowing for real-time interaction and analysis of mobility data. This functionality

supports a wide range of applications, including traffic management, transport planning, and sustainability analysis.

This interaction model ensures that participants engage productively with the platform, enabling an ecosystem that supports diverse use cases in the mobility sector, promoting transparency, data accessibility, and cross-sector collaboration within the IMDS.

4.2.4.11 User Interface

The UI (User Interface) component ensures that the IMDS platform is accessible, user-friendly, and supports sustainable transportation goals by streamlining user interaction:

- **Intuitive Interface:** A well-structured interface enables easy dataset search, metadata viewing, and access to reporting tools. Interactive dashboards provide clear visual insights to enhance data usability.
- **Comprehensive Documentation and Onboarding:** Detailed guides, tutorials, and documentation facilitate onboarding and ongoing support, covering essentials like data discovery, API integration, and data-sharing protocols.
- **Responsive and Inclusive Design:** The platform's design is optimized for a wide range of devices and complies with accessibility standards (e.g., Web Content Accessibility Guidelines - WCAG), ensuring usability for all demographics, including individuals with disabilities.
- **Transparent Security and Data Management:** UX includes secure authentication and clear data-sharing policies, building user trust by clarifying data usage and management practices.

This user-centred approach ensures that stakeholders, from policymakers to app developers, can navigate the IMDS efficiently. By prioritizing an intuitive and transparent UX, the IMDS supports data-driven decision-making, encouraging user engagement and promoting sustainable urban mobility solutions across Ireland.

4.3 Challenges of IMDS

Stakeholder Coordination

In the IMDS, **stakeholder coordination** is a critical yet challenging aspect of establishing a unified and effective governance framework. The IMDS encompasses a wide array of stakeholders, including public authorities like the National Transport Authority, private mobility providers such as ride-sharing and public transport operators, and intermediaries such as MaaS operators, and other services providers. Each of these entities has unique objectives, interests, and operational priorities, which can create barriers to seamless collaboration.

Public Authorities, for example, may prioritise compliance with national policies and EU regulations, focusing on accessibility, sustainability, and public interest goals. On the other hand, **private companies** may be driven by profitability, competition, and data monetisation opportunities. Similarly, **citizen groups** are likely to prioritise privacy, transparency, and equitable access to mobility services. Balancing these diverse priorities under a unified governance model requires significant effort.

Conflicting interests can slow down **decision-making and adoption** within the IMDS. For instance, private companies may hesitate to share proprietary data due to competitive concerns, while public

authorities may enforce stringent regulations to safeguard public interest, delaying the approval of operational frameworks. Additionally, citizen groups may challenge initiatives they perceive as invasive to privacy or inequitable, creating further resistance.

Data Ownership and Sovereignty

In the context of the IMDS, **clarifying data ownership rights** is a critical challenge. Mobility data often originates from a variety of sources, including public transit systems, private operators, and citizen-generated data through apps and IoT devices. Determining who owns the data—whether it is the provider, the processor, or the individual generating it—can lead to disputes, especially when private stakeholders are involved.

Additionally, the IMDS must ensure that data sharing adheres to **sovereignty principles**, particularly within the framework of EU regulations like GDPR and the Data Governance Act. Data sovereignty dictates that data remains under the jurisdiction of the originating country or organisation, complicating international data sharing. For example, Irish mobility data shared with EU-wide systems must maintain compliance with Ireland's national laws while aligning with EU-level standards, raising potential conflicts over governance and control.

Cross-Jurisdictional Issues

The IMDS operates within a legal and regulatory landscape that spans **local, national, and EU frameworks**. Differences in regulations across these levels create significant challenges in achieving compliance and interoperability. For instance, while GDPR provides a unified data protection framework across the EU, additional Irish laws, such as the Data Sharing and Governance Act 2019, may impose further obligations on data sharing.

Private sector stakeholders, particularly those operating internationally, may face difficulties aligning their data practices with overlapping and sometimes conflicting regulations. This complexity is further heightened in cases involving cross-border mobility data, such as coordinating transport systems or emissions tracking across Ireland and neighbouring EU states.

Liability and Accountability

The question of **who is liable** for issues such as data misuse, breaches, or inaccuracies presents a major challenge in the IMDS. Data flows across multiple entities, including providers, processors, and consumers, making it difficult to assign accountability. For example, if an inaccurate dataset from a mobility app leads to operational disruptions, determining whether the responsibility lies with the app developer, the data space operator, or the end-user can be contentious.

Additionally, as mobility data is shared and processed within the IMDS, liability frameworks must address potential risks such as data breaches, privacy violations, and misuse of proprietary information. Without **clear accountability mechanisms**, stakeholders may hesitate to share data, fearing financial or reputational damage in the event of legal disputes or breaches.

Trust Among Stakeholders

Trust is a cornerstone for the success of the IMDS, where collaboration among public authorities, private companies, SMEs, and citizens is essential. However, building trust among these diverse stakeholders is inherently challenging. Concerns about **data misuse, unfair competition, and lack of transparency** often create barriers to participation. For instance, private companies may hesitate to share proprietary data,

fearing it could be misused by competitors or leveraged against them in the marketplace. Similarly, public authorities may worry about potential breaches of public trust if shared data is mishandled, while citizen advocacy groups may raise concerns about privacy and ethical use.

Addressing these concerns requires robust **governance frameworks** that prioritise security, ethical data use, and fairness. Transparent mechanisms for **data access, usage, and auditing** must be established to reassure stakeholders that their contributions will not lead to negative consequences. Moreover, fostering collaboration through clear agreements and joint incentives, such as co-developed projects or shared economic benefits, can help mitigate resistance and create a cooperative environment.

Public Engagement and Awareness

Public engagement is equally critical for the adoption and success of the IMDS. Citizens, as both contributors to and beneficiaries of the data space, must understand its value and feel confident in how their data is handled. **Misunderstandings or mistrust** about data privacy or potential misuse can significantly limit public participation, thereby undermining the effectiveness of the IMDS.

To address this, targeted **educational initiatives** are necessary. These could include workshops, public awareness campaigns, and user-friendly platforms that explain the benefits of the IMDS, such as improved public transport, reduced emissions, and better urban planning. Transparent privacy policies and tools that allow citizens to control their data, such as **dynamic consent mechanisms**, can further enhance trust and encourage participation.

Additionally, engaging with community leaders, advocacy groups, and local organisations can help amplify outreach efforts, ensuring that the IMDS is seen as a collaborative, citizen-centric initiative. By prioritising transparency, inclusivity, and education, the IMDS can foster widespread acceptance and establish itself as a trusted platform for mobility innovation in Ireland.

5. Conclusion

The IMDS has the potential to redefine transportation in Ireland, setting a new standard for innovation, sustainability, and inclusivity. By harnessing the power of data sharing through Mobility Data Spaces, Ireland can transform its transport sector into a model of efficiency and environmental responsibility. This report has explained how Irish Mobility Data Space can address key challenges, from multimodal integration and Mobility as a Service platform to optimised EV infrastructure, while fostering collaboration across public, private, and community stakeholders.

The IMDS is more than just a data sharing ecosystem—it can be the strategic enabler for achieving Ireland's climate targets, improving public service delivery, and enhancing citizen and goods mobility. The governance structures, technical architectures, and compliance frameworks proposed in this report provide a robust foundation for building a national data sharing infrastructure for transport sector in Ireland. These elements, combined with an emphasis on stakeholder engagement and trust, create a pathway to an ecosystem that is not only functional but transformative.

If Ireland embarks on this ambitious journey, the subsequent steps will be pivotal in determining its success. A pilot project utilizing the minimum viable Irish Mobility Data Space (IMDS) will act as a proving ground, showcasing the feasibility and potential impact of the IMDS while enabling its refinement through real-world insights. The successful execution of the pilot project will generate valuable knowledge, informing decision-making for the implementation of the full-scale Irish Mobility Data

Space. By adopting a phased implementation approach, underpinned by rigorous monitoring and evaluation processes, the IMDS will be equipped to scale effectively, address emerging challenges, and deliver measurable benefits to all stakeholders.

The outlook for the IMDS is one of immense promise. With bold action and a commitment to innovation, Ireland can position itself as a global leader in sustainable mobility. The IMDS has the potential to do more than solve immediate transportation challenges; it can inspire a cultural shift toward smarter, greener, and more connected living. It will empower communities, drive economic growth, and set a benchmark for how data can be leveraged to tackle the most pressing issues of our time.

The challenges Ireland faces in its transportation sector are significant, yet the opportunities for transformative progress are equally substantial. Positioned at the forefront of a global shift towards sustainable and intelligent mobility, Ireland has the potential to lead by example through the implementation of the Irish Mobility Data Space (IMDS). As outlined in this report, the strategies and frameworks proposed offer a pathway to establish a pioneering mobility system that exemplifies innovation, efficiency, and environmental stewardship.

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