

ReNEW

D3.2 - Green Resilient IWT (GRIWT)
Dataspace and generic Digital Twin
Architecture v2



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Document Info

Document

Title	Resilience-centric Smart, Green, Networked EU Inland Waterways
Acronym	ReNEW
Call	HORIZON-CL5-2021-D6-01
Type of Action	HORIZON-IA
Grant Number	101069682
Start date	1 September 2022
Duration	36 months
Document identifier	D3.2- Green Resilient IWT (GRIWT) Dataspace and generic Digital Twin Architecture v2
Due Date of Delivery to EC	29-02-2024
Actual Date of Delivery to EC	27-02-2024
Dissemination level	PU - Public
Work package	WP3 - European IWT Data Space and Digital Twin solutions for Resilience and Sustainability
Lead Beneficiary	IMEC

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History Sheet

Version	Date	Editor	Summary of Modifications
0.1	20/12/2023	Tom Bergmans	First draft & table of content
0.2	08/01/2024	Philippe Michiels	Architecture update
0.3	09/01/2024	Birger Schrevens	Use case update
0.4	11/01/2024	José Luis Lopez Ramon	Update chapter 5
0.5	24/01/2024	Antonis Antonopoulos	Update chapter 4
0.6	26/01/2024	Remi Sigronde	Update chapter 6
0.7	29/01/2024	Birger Schrevens, Tom Bergmans	Edit for review
0.8	10/02/2024	Filipe Martins Tamás Krámer Nik Delmeire	Review
1.0	27/02/2024	Birger Schrevens Tom Bergmans	Final editing

Acronyms and Abbreviations	
AI	Artificial intelligence
AIS	Automatic Identification System
AIOTI	Alliance of Internet Of Things Innovation
APDL	Administração dos Portos do Douro, Leixões e Viana do Castelo
API	Application Programming Interface
BDIS	Big Data Infrastructural Services
BPMN	Business Process Modelling Notation
CI	Critical Infrastructure
DID	Distributable Identities
DT	Digital Twin
DUET	Digital Urban European Twins
ETSI	European Telecommunications Standard Institute
GA	Grant Agreement
GIS	Geographic Information System
HTTP	Hypertext Transfer Protocol
ICS	Institute for Corporate Security Studies
IDS	International Data Spaces
IT	Information Technology
IDSA	International Data Spaces Association
IWT	Inland Waterway Transport
KG	Knowledge Graph
KPI	Key Performance Indicator
LDES	Linked Data Event Stream
LDI	Linked Data Interactions
LDIO	Linked Data Interactions Orchestrator
LL	Living Lab
ODT	Open Digital Twin
ParIS	Participation Infrastructure
RL	Reinforcement Learning
SDK	Software Development Kit
SDP	Smart Data Platform
TRL	Technology Readiness Level
UX	User Experience
VR	Virtual Reality
VSDS	Vlaamse (Flemish) Smart Data Space
WFS	Web Feature Service

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Executive Summary

ReNEW is the acronym for the project "Resilience-centric Smart, Green, Networked EU Inland Waterways". This project is funded by the European Commission under the topic "HORIZON-CL5-2021-D6-01-09 "Climate resilient and environmentally sustainable transport infrastructure, with a focus on inland waterways".

In this document imec presents an update on ReNEW's Green Inland Waterway Transport system Data Space and Digital Twin solution as an innovative decision support system allowing decision-makers to enhance sustainability and resilience in the inland waterway Transport system.

Imec provides an architectural outline refining its D1.1 deliverable based on RENEW LivingLab requirements and insights gathered from ReNEW's work package 1 on "Methodology for EU Resilient and Sustainable IWT Infrastructure System".

We introduce an architecture and technical components that allow decentralized data sources to be integrated through the means of a Data Space. This Data Space is connected optimally to algorithmic model providers and a Digital Twin interface by using Linked Data Event Streams, resulting in optimal accessibility of data for a Digital Twin application and for data consumption by RENEW internal stakeholders (e.g. for research purposes).

Consequently we delve deeper into the setup of the Data Space and Digital Twin from an architectural and from a deployment perspective. We describe the identified data sources to be integrated and expected to be available for ingestion in the coming period, a criterion of prioritization used by Work Package 3 as some LivingLab Digital Twin related requirements hinge on data sources that are not available at the moment of this writing as they depend on the creation and implementation of hardware components that are equally an outcome of the ReNEW project.

Finally the LivingLab requirements – acquired through multiple LivingLab scoping sessions are longlisted and these longlists serve as a basis for selecting two 'common denominator' use cases where feasibility (of available data sources) and desirability (how can we maximally cover the needs of the LivingLabs) as selection criteria go hand in hand to guide us to a navigability and transport mode comparison use case to be deployed as a ReNEW Digital Twin capabilities.

1 Introduction

This document is the second deliverable within task 3.1 of the ReNEW project. Its content elaborates on the D3.1 Framework architecture and core infrastructure components definition [1]. In this sense this deliverable is not to be seen as a standalone exhaustive document, yet it is to be considered as an addition and a refinement of the 3.1 deliverable based on evolutions within and insights gathered from interactions with the ReNEW project partners of Work Package 1, 2 and 4 and from deliverables that are the result of proceedings of these work packages.

Mapping the ReNEW Output

1.1 *Table 1* maps the ReNEW's Grant Agreement (GA) commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work to perform.

Table 1: Adherence to ReNEW's GA Deliverable & Tasks Descriptions

Deliverable D3.2: Green Resilient IWT (GRIWT) Dataspace and generic Digital Twin Architecture v2		
Agile Architecture specification, with Proof-of-Concept applications in LLs.		
Task T3.1: Green Resilient IWT (GRIWT) Dataspace and generic Digital Twin Architecture		
Define the generic architecture for IWT evidence-based decision support solutions. Operationalise the software and hardware components that can be implemented and integrated. Provide the building blocks serving as baseline supporting the planning, operation and evaluation and the impacts assessment of modular floating platforms and autonomous barges (WP2) and the interventions related to increasing the resilience and sustainability of infrastructure and vessel resources in the Living Labs		
ReNEW GA Element Title	ReNEW GA Element Outline	Respective Document Chapter (s) and Description
ST3.1.1 Architecture based on Living Labs and Technical backlog definition	Design the overall ReNEW system architecture which glues models (functions) with data spaces/digital twins. The ReNEW architecture shall ensure that the digital twins can access the data, providing fast access and scalability, and will accommodate all provisions for security and privacy preserving measures at all levels, i.e., data, models, operational structure, communication. Apply the ReNEW agile process (involving the modelling of users needs as user stories and the creation of user story maps), to capture the digitalization needs and support from the Digital Twins, the Data Spaces, and the solutions and services developed for the Living Labs. Draft guidelines on how to construct the ReNEW digital twins and data spaces architecture, also considering interoperability with outputs of existing initiatives such as the DTLF, FENIX, and FEDeRATED.	D3.2 Framework Architecture (covered by this deliverable)

2 A Combined Architecture - Update

Inland waterway transport is a crucial mode of transportation for the movement of goods and passengers across Europe. To enhance the efficiency, safety, and sustainability of inland waterway transport, this project proposes a comprehensive digital infrastructure that integrates data spaces, digital twin technology, and Linked Data Event Streams (LDES). This architecture aims to provide real-time insights into waterway conditions, enabling predictive navigability models and supporting informed decision-making for stakeholders across the inland waterway sector.

In this chapter we dive deeper into the proposed architecture that combines dataspace and digital twins. First we map the use case(s) of the living labs onto this architecture. Second, we propose a design pattern for integrating models with the data streams and the digital twin. Finally, we discuss in detail the LDES building blocks that are being integrated into the architecture.

Architectural Overview

2.1 The architecture proposed in ReNEW deliverable D3.1 [2] aims to leverage LDES to create a uniform, scalable, and reliable data publication mechanism that supports efficient data exchange, historical data access, and robust predictive modelling for enhanced navigation safety and efficiency in inland waterways. The architecture delivers on these goals as follows:

2.1.1 Uniformity in Data Publication:

By utilizing LDES, the architecture ensures a consistent and standardized format for data publication. This uniformity benefits data publishers by providing a single, well-defined mechanism for disseminating their information. It also promotes interoperability between different data sources, facilitating seamless integration and exchange of data.

2.1.2

Scalable Data Publishing Strategy:

The use of LDES enables a scalable data publishing strategy for participants. LDES's inherent event-driven nature allows for incremental updates to data streams and its exploitation of ubiquitous HTTP optimizations allows for handling large volumes of data without overwhelming the publishing infrastructure. This scalability is crucial for maintaining the performance and responsiveness of the overall system.

2.1.3

Access to Historical Data:

LDES data consumers, such as algorithms and the digital twin environment, have access to the full historical record of published data. This complete access to past data is essential for applications like predictive navigability modelling, where historical patterns and trends play a key role in forecasting future conditions. A historical dataset serves as a valuable resource within the digital twin environment, enabling a strong foundation for both machine-made simulations and human analyses.

Robust and Scalable Approach:

2.1.4 The combination of data spaces, digital twins, and LDES within this architecture provides a robust and scalable approach for fulfilling the goals of Digital Inland Waterway Management. The data spaces offer a centralized repository for managing and sharing inland waterway data, while the digital twin provides a real-time representation of the waterway system. LDES acts as a communication backbone, enabling seamless data exchange between these components.

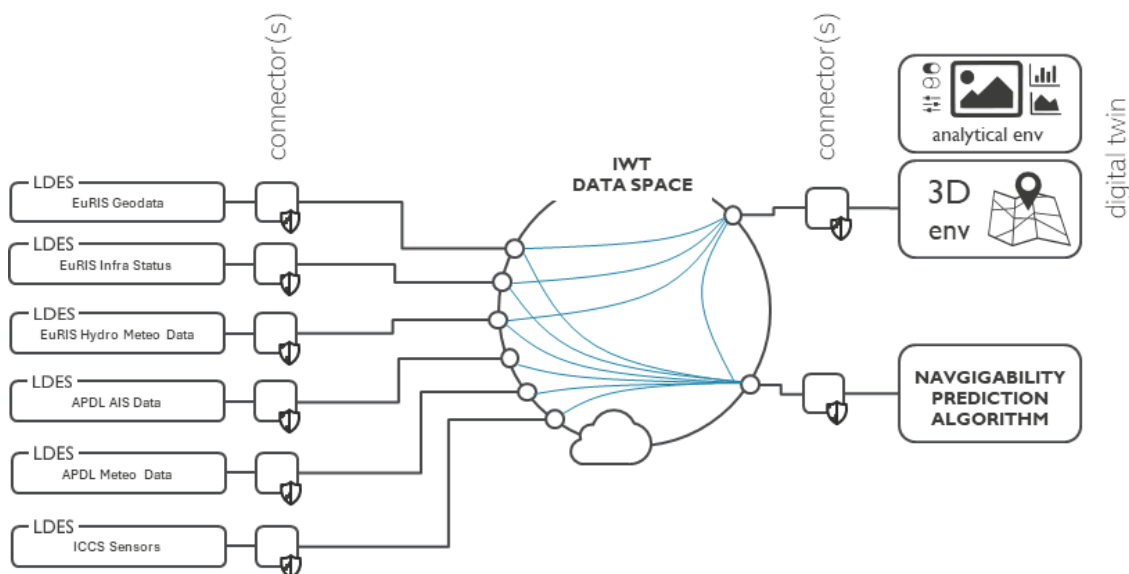


Figure 1: A high-level overview of the proposed architecture applied to the common use case

2.2 Figure 1 gives an overview of the proposed architecture. The data sources are published through dataspace connectors. Independently of the deployment, models and decision support tools such as digital twins can discover and consume the data sources. Linked Data Event Streams are the backbone for the scalable and robust architecture supporting such tooling.

Design pattern for Algorithmic Decision Support

LDES is a multi-purpose data publication protocol that leverages HTTP's ubiquity, simplicity and scalability. As such it can be used to harmonize data flows for decision support systems. The Navigability use case (see 6.1.1) combines several data sources in a model to predict the navigability of Inland Waterways. By providing an abstract interface for models in terms of input and output data streams, these models can be applied anywhere provided that the data streams are published as LDES streams. The set of tools presented in section 3.3, can be used to do this fairly quickly.

The assumption that data sources, models and other components are typically not deployed centrally requires a way of streaming data efficiently between all components (data sources, algorithms, users, ...), regardless of their respective deployment locations. A distributed deployment also means that little or no assumptions can be made in terms of connectivity/availability. This adds the requirement

that every component must be capable to operate independently from the other components and that recovery from disconnections should be possible (e.g. one data source is temporarily offline). LDES is specifically designed to ensure this.

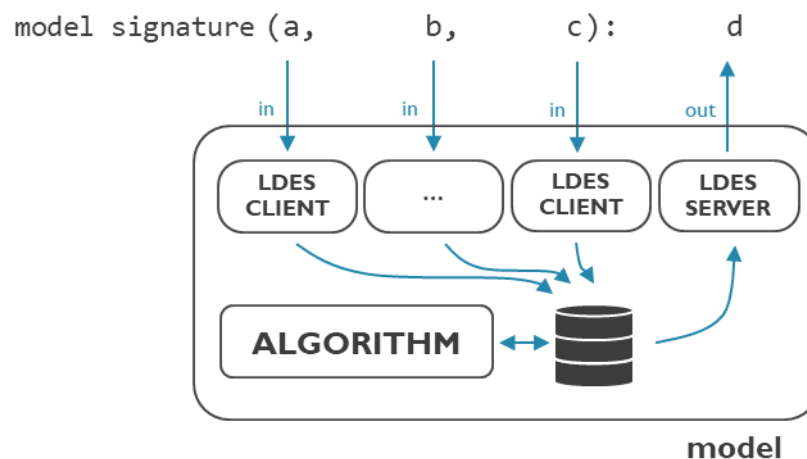


Figure 2: A model signature represents an abstract interface for models. LDES is perfectly suitable to implement such an interface robustly.

Figure 2 presents a design pattern for integrating models in such a disconnected environment. Inspired by DUET [3], this pattern has been specified with the following requirements in mind:

1. **Separation of concerns:** The approach separates the concerns of data ingest/output, data storage and (algorithmic) data processing. This approach promotes interoperability and thus also reusability of the algorithm;
2. **Abstraction from protocols, schemas and formats:** The data input/output can be isolated and abstracted from its protocols, schemas and formats. Although we are suggesting the use of LDES, other protocols/systems such as Kafka can be supported in the same way. The importance is that the model signature is well-documented;
3. **Composability:** Often, the output of one model is part of the input of another model. Our generic approach allows to compose models and abstracting from protocols and formats is helpful in that regard;
4. **Resilience:** when models are not centrally deployed, it is hard to make assumptions about availability. The design pattern enables recovering from service disruption by relying on the LDES principle of getting in sync and staying in sync.

A model signature provides all the metadata required for a user to understand and make use of the model. This includes information about supported protocols, data schema and format, but also assumptions made by the model in terms of quality, volume and resolution of data inputs and the same qualitative attributes for the outputs.

In order to connect data sources and model output data streams with decision support systems and analytical tools, the many available LDES client adapters that are built on the LDES client SDK can be used to stream data to fit-for-purpose systems such as time series databases, IoT context brokers, WFS systems, etc. An example setup for this is illustrated in Figure 3, below. More information on this can be found in the [official documentation of the interaction building blocks of LDES](#).

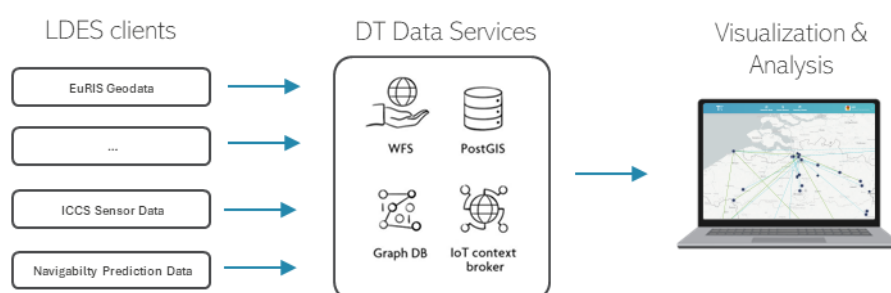


Figure 3: Using the LDES client SDK or ready-made LDES2Service adapters, data can be captured into fit-for-purpose systems that are deployed within the decision support environment for smooth analysis and visualization.

2.3 Implementing LDES

Linked Data Event Streams (LDES) apply the concept of linked data to data streams. LDES is a technical standard that allows data to be exchanged sustainably and cost-effectively between silos using domain-specific ontologies. This is both for fast and slowly changing data streams [4].

A Linked Data Event Streams deployment typically involves the components as described below in this subsection. Technical information guides, tutorials and examples on LDES can be found on Github for each of the involved building blocks and used protocols or standards [5].

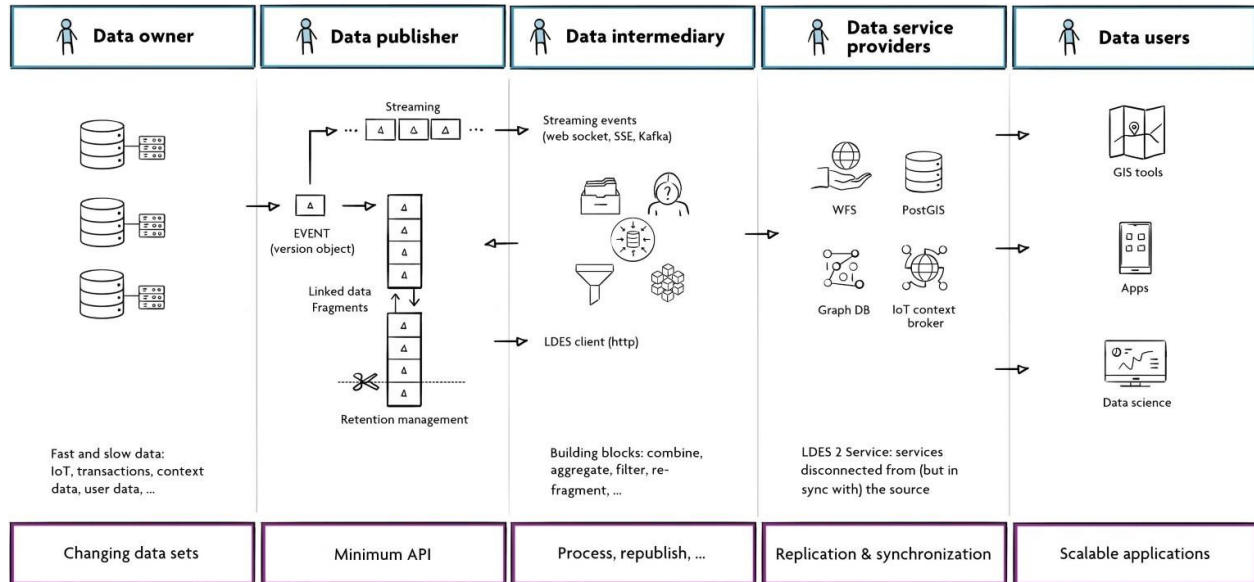


Figure 4: The data publisher only serves HTTP cacheable data fragments with a specified retention period and complex queries and heavy query load are diverted to services closer to the (machine or human) data user. The data service provider can always get in sync & stay in sync. After a disruption recovery is trivial to get back in sync.

2.3.1

LDES Server

The Linked Data Event Stream (LDES) server is a configurable component that can be used to ingest, store, and (re-)publish one or multiple Linked Data Event Stream(s) as depicted by **Figure 1**. The open-source LDES server is built in the context of the VSDS project to exchange (Open) Data easily [6].

2.3.2

LDES Client

The LDES CLIENT is designed for replication and synchronisation, meaning the client can retrieve members of an LDES but also checks regularly if new members are added and fetches them, allowing data consumers to stay up to date with the dataset.

To understand the functioning of an LDES client, it is important to understand how LDESes are published on the Web. The Linked Data Fragments principle is utilised for publishing an LDES, meaning that the data is published in one or more fragments and meaningful semantic links are created between these fragments. This approach facilitates clients to follow these links and discover additional data. However, the critical aspect for the LDES client is the notion of mutable and immutable fragments. When publishing an LDES stream, a common configuration is to have a maximum number of members per fragment. Once a fragment surpasses this limit, it is regarded as immutable, and a 'Cache-control: immutable' cache header is added to the fragment to signify this. This information is crucial for the LDES client since it only needs to retrieve an immutable fragment once, while mutable fragments must be regularly polled to identify new members.

LDES Connectors

The Linked Data Interactions project (LDI) [7] is an effort to make interactions with Linked Data more fluent by providing easy building blocks. Currently, two frameworks to use these building blocks are supported:

- 2.3.3 • Linked Data Interactions Orchestrator: A lightweight application
- Apache Nifi: A powerful system to easily process and distribute data

The LDI project is open source and is open for contribution and collaboration to everyone who wants to chip in. Using LDIO, the Linked Data Interaction Orchestrator, an LDES data pipeline can be set up really quickly. Multiple input/output terminators, adapters and transformers are available. There are adapters for file, Kafka and HTTP (among others), but others can be added fairly quickly. For a full list we refer to the available documentation [8].

In the next section 3.4, the document will focus more on the building blocks in the setup. The section thereafter, section 3.5, will focus on the practical implementation. Note that this document is part of an incremental versioning of the full deliverable about the framework architecture. A planned third iteration of this document will hold a report-back on the use of these components aligned with the practical & common use cases, as well as possible improvements or contributions to the repositories.

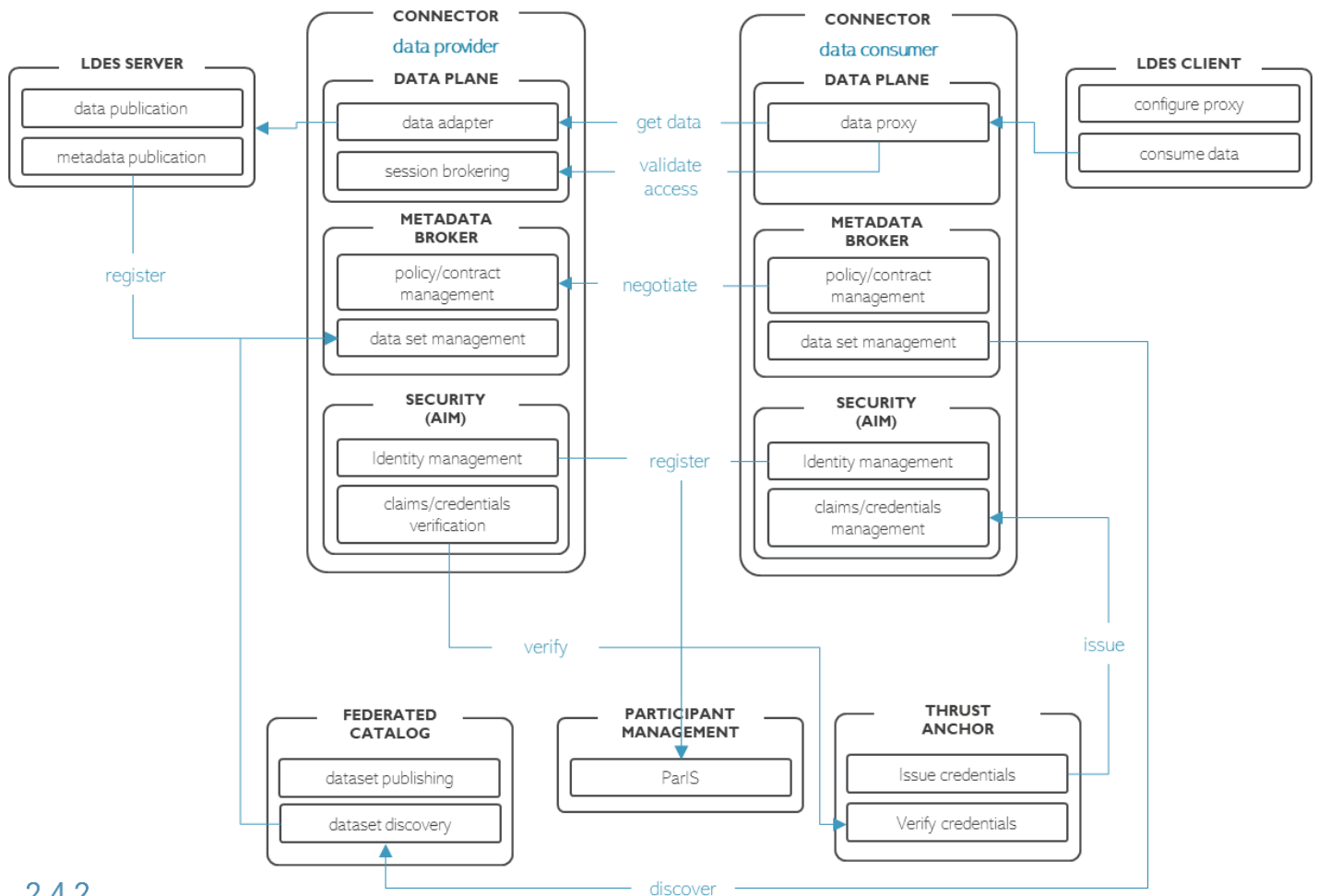
2.4 IWT Dataspace

The ReNEW project aspires to deliver building blocks to allow participants to exchange data in a dataspace for Inland Waterway Transport data. For this, the ReNEW project will rely on components delivered by the Eclipse Foundation [9] and components delivered by the Flanders Smart Dataspace Project (VSDS) [10], of course all in accordance with the general principles and framework guidelines of the IDSA (International Data Space Association) [11].

2.4.1

Functional Architecture

The following architecture depicts the functional building blocks of the IWT dataspace. They are discussed below in more detail. The architecture provides several features for users, including efficient management and processing of large amounts of data, secure identity management, claims/credentials verification, and a federated catalog for dataset publishing and discovery. The LDES server can be configured to meet the specific needs according to the already discussed requirements above. The system is designed to allow clients to replicate the history of a dataset and efficiently synchronize with its latest changes. The Linked Data Event Stream (LDES) is the chosen data publishing approach as it allows you to publish any dataset as a collection of immutable objects. The focus of an LDES is to allow clients to replicate the history of a dataset and efficiently synchronize with its latest changes. The LDES server is a configurable component that can be used to ingest, store, and (re-)publish one or multiple Linked Data Event Stream(s). The other components are standard data space building blocks. More information on each of these is provided in the next sections.



2.4.2

Figure 5: Functional building blocks of the IWT data space

Functional Buildingblocks

Connectors

Connectors are components that bundle the functional aspects of exchanging data within a data space. They facilitate (i) connecting to a data space, (ii) publishing and discovery of datasets, (iii) negotiation of contracts and (iv) exchange of data sets by providing corresponding APIs.

Identity management

Users have to be able to configure the identity they want to use to participate in the Data Space. Next to configuration, the identity should be manageable (deleting, updating, ...). The identity is used to authenticate your identity with other data space participants such as data providers, data consumers, participation management services and brokers.

Connectors use decentral identities (DIDs) for identifying an individual or organization. DIDs are a new type of identifier that enables verifiable, self-sovereign digital identities. Unlike traditional identifiers provided by centralized services (like social media handles or email addresses like gmail), DIDs are owned and controlled by the individual, organization, or entity they represent.

DIDs are typically stored in a credentials wallet (part of the connector), that allows the connector to present identities and credentials when needed for accessing data sets in the Data Space.

Metadata broker

The metadata broker is responsible for collecting and publishing metadata for data sources published by participants and is part of the connector. The broker enables a participant to make his data sources visible in the Data Space. Based on the participant list in the Participant Information System (ParIS) a Federated Catalog Service can discover, collect and publish the metadata in a centrally accessible service, making them easy for others to find.

Policy management

Contracts (or agreements) between the publisher and consumer are required before transfer of data can take place. These contracts can be created based on policies that prescribe the conditions for use of the dataset. Open Digital Rights Language (ODLR) is one of the standards that can be used to specify such policies in a machine-readable way. The component enables to create, consult and update policies for datasets that the provider wants to offer.

Contract negotiation

A participant can agree to the conditions for data usage as specified in the policy, by creating a contract with the data publisher. The contract negotiation component allows to accept or reject contracts for datasets which the consumer wants to consume, either automatically or manually.

Data plane

Actual exchange of the data happens through a Data Plane of the Connector. These connectors can support different connectivity protocols such as HTTP, FTP, ... In this case, LDES (which uses HTTP) was chosen as the protocol. The access to an LDES will be managed by the data plane. As such, the connector will act as a gateway for the LDES Server that deals with security and access management.

Participant Information Service (ParIS)

ParIS (Participant Information Service) is a pivotal component within a data space, serving as an identity and discovery service. It catalogs participants in the data space, detailing their identities and services, thereby facilitating interoperability and streamlined collaboration among various stakeholders. Essential for maintaining trust and security, ParIS ensures that data exchanges occur within a reliable and verified network. It simplifies the complexity inherent in navigating a data space, enhancing data governance, and supporting scalability as more participants join. Ultimately, ParIS is fundamental to the efficient operation and governance of data spaces, enabling secure and effective data sharing across diverse entities.

Federated catalog

The Federated Catalog in a data space acts as a collective repository that aggregates and indexes data offerings from various participants. It allows for the unified search and discovery of data across different entities, enhancing accessibility and utility of the data space. By federating catalogs from multiple sources, it creates a comprehensive view of available data, making it easier for participants to find and utilize the data they need.

It makes sense to combine the governance and deployment of the ParIS and the Federated Catalog for managing dataspace in general and the European IWT dataspace in particular.

Thrust Anchor

A trust Anchor refers to the entity that issues certifications about an attribute of an identity. A trust framework is a set of rules imposed by the trust anchor to comply with its policies in order to be eligible for its attribute verification. Deciding which trust anchors and trust frameworks and, therefore which rules and procedures to use for issuing and validating attributes, is the task of the data space authority (DSA).

Data Services (LDES Server& Client)

In order to efficiently transport fast moving and slow moving data, LDES (Linked Data Event Streams) is used as a protocol. It is built on top of HTTP, minimizing any adaptations required by standard connector infrastructure.

2.4.3

Technical Components

IWT Connector

A dataspace connector based on the EDC (Eclipse Dataspace Connector) with adapters for serving LDES data and consuming LDES data.

IWT Participant Management System

The existing components offered by iShare [12] , notably the iSHARE satellite, are a good candidate for fulfilling participant management and discoverability in de IWT dataspace.

IWT Federated Catalog

This role can either be fulfilled by a dedicated aggregator connector that collects and publishes data from connected participants. Another option is to set up an iShare satellite (which is needed for participant management anyway) and use its catalog feature.

LDES Server

The LDES server reference implementation allows to quickly set up and configure LDES data streams [13].

LDES Client

An LDES client SDK is available and can be used as a foundation for re-publishing LDES data in fit-for-purpose services such as Context Brokers and WFS Services. Some adapters have already been published and can be set up with little or no coding [14].

3 Data Space Architecture – Implementation LL Update

The digital twin is both a producer and a consumer of data. The consumed data often originates from sources over which the contributors of ReNEW Work Package 3 may have little or no influence, necessitating adherence to the appropriate data acquisition methods. Similarly, the destinations for the data produced by the digital twin may also be beyond our control, requiring us to conform to established communication protocols. On the other hand, there are scenarios where the other party is open to establishing a mutually beneficial method of communication. This is where the concept of data spaces, with its emphasis on data sharing, becomes relevant. Nonetheless, it's important to note that the more common scenario involves adapting to the existing communication frameworks that are already in place.

In the ongoing implementation phase, our primary focus is on integrating data essential for supporting the LL use cases. Concurrently, we are deploying an architecture designed to not only meet current needs but also to support an advanced dataspace concept, being adaptable and scalable for future advancements and integrations in the realm of data sharing and management.

In the upcoming sections, we first introduce the prioritized data sources. This discussion leads to the introduction of the corresponding data acquisition methods, which have been integrated into specific microservices. These microservices collectively form a comprehensive connector library. Next, we detail the implementation of the digital twin components that are crucial for data propagation and management. This implementation is discussed in relation to the specifications outlined in the previous version of this deliverable, providing continuity and highlighting the evolution of our approach.

Selection of Data Sources

This section provides a summary of the data sources selected for integration into the dataspace. A detailed justification for these selections, along with information about the technological aspects of their integration, is available in Deliverable D3.4 Green Resilient IWT Dataspace components solutions 3.1 and tools v1 [15].

- The European River Information System (EuRIS) [16] is a vital data source that offers comprehensive and real-time information relevant to inland waterway conditions. This integration is driven by several key characteristics:
 - **Relevance and Accuracy:** EuRIS provides data that is highly pertinent to the operational and environmental aspects of inland waterways. Its accuracy is essential for creating a reliable digital twin model that can effectively simulate and predict waterway conditions.
 - **Enhanced Resilience:** The inclusion of EuRIS data aids in building a more resilient system. By having access to real-time and historical data on water levels, flow rates, and weather conditions, the digital twin can better anticipate and respond to various scenarios, ranging from daily operational challenges to extreme weather events.
 - **Operational Efficiency:** Integrating EuRIS helps in optimizing waterway management. By leveraging its data, the digital twin can provide actionable insights for efficient routing, maintenance scheduling, and emergency response planning.
 - **Collaborative Approach:** Utilizing EuRIS aligns with our collaborative approach, allowing us to tap into established data networks and expertise. This integration not only enhances the digital twin's capabilities but also fosters partnerships with key stakeholders in the inland waterway sector.
 - **Scalability and Future-Proofing:** Incorporating EuRIS sets our digital twin up for future scalability. As EuRIS evolves and expands its data offerings, our digital twin can seamlessly adapt, ensuring it remains a state-of-the-art tool for inland waterway resilience.
- Weather Service Providers: Incorporating real-time meteorological updates from weather service providers enhances the digital twin's accuracy and responsiveness. Information on temperature, precipitation, wind patterns, and more allows the twin to anticipate disruptions, optimize operations based on current weather, and offer timely recommendations to stakeholders.
- Water Level and Water Quality Sensors: Understanding the depth and quality of water is a key element in managing and operating waterways. The digital twin, enhanced by the integration of water level sensors, can evaluate navigability, forecast possible flood events or decreasing water levels, and streamline vessel navigation. In parallel, sensors that measure water quality offer valuable data on aspects such as pH, turbidity, dissolved oxygen, and contaminants. This information is vital not only for assessing environmental conditions but also for guiding the use of waterways. It becomes particularly important in situations where water quality is a critical factor, like near freshwater intake points or in ecologically sensitive areas. Note that the onboarding of water quality data into the digital twin is not yet explicitated in the Digital Twin use cases.

- AIS Receivers: The Automatic Identification System (AIS) is a crucial component for ensuring maritime safety and navigation. Through the integration of data from AIS receivers, the digital twin gains access to live information regarding the positions, directions, velocities, and other specific characteristics of ships. This information plays a key role in overseeing marine & inland-waterway traffic, evaluating congestion in harbours or waterways, foreseeing possible collision risks, and improving navigation routes. Additionally, the insights gained from AIS data contribute to a better understanding of ship movements and patterns, thereby enhancing maritime & IWT situational awareness and increasing operational efficiency.

Digital twin components related to data propagation and management

3.2

ReNEW Deliverable 3.1 [17] specifies the components required for the digital twin to successfully conduct the anticipated tasks. Within these, we distinguish those components and tools specifically related to the dataspace:

3.2.1 Asset Catalog

The asset catalog is an essential tool in digital twin environments, providing a detailed overview of datasets, schemas, vocabularies, and algorithms. It ensures datasets are trustworthy and of high quality, adhering to Smart Data Management principles. This includes a clear understanding of the dataset's lineage, integrity, and applicability. The catalog also lists available data formats and tracks data schemas and vocabularies, ensuring schematic and semantic compatibility with various tools. Additionally, it documents algorithms in terms of their data inputs and outputs, aiding in compatibility assessments and understanding their potential in terms of quality and reliability. Beyond algorithms, the catalog includes other building blocks like simulation models, essential for data transport or transformation.

3.2.2

Message broker

The message broker plays a crucial role in the digital twin ecosystem by enabling communication between models, data sources, and other components. It orchestrates data flow, directing it from data sources to models, among models, and towards other elements like the visualization client. User interactions with the digital twin environment trigger messages through the message broker, ensuring that other components can respond accordingly. Such functionalities are commonly managed by a message streaming platform, for example, Kafka.

Interaction/orchestration service (data provisioning perspective)

The interaction or orchestration service plays a pivotal role in data integration for simulation environments. It is tasked with interpreting the specifics of a scenario as outlined by the scenario manager and converting these details into a cohesive and executable data flow. This process involves integrating various data sources and ensuring seamless data communication among different components of the simulation. The service is also responsible for managing the initiation, pausing, and termination of simulations in accordance with the defined scenarios, as well as for the storage and integration of simulation outcomes.

A critical function of this service is treating interactions themselves as integral data sources. This approach allows models within the simulation to dynamically respond to changes in the data landscape. For example, in the event of a street closure, the service seamlessly integrates this new data, enabling traffic flow models to recognize the change and adjust their predictions accordingly. This exemplifies the service's capability to not only manage but also intelligently integrate diverse data streams, ensuring a responsive and adaptive simulation environment.

3.2.4 Digital twin management

A dedicated management module is essential for various administrative tasks in the digital twin environment. It handles initial setup, user onboarding, and access control. Key functions of this module include managing administrative users, assisting with issues like locked accounts, overseeing the asset catalog and its external connections (such as syncing with other catalogs), conducting audits and monitoring of components like the message broker, and registering third-party identity providers, among other responsibilities.

Figure 6 illustrates the implementation adopted to facilitate the operation of a digital twin, primarily focusing on the dataspace perspective, where the above components have been considered and included. A detailed description of this implementation is provided in D3.4 [18]. A messaging system is employed to distribute data, events, and triggers to various peripheral components. Data storage, both permanent and temporary, for configuration, data, and metadata, is managed through a combination of a time-series database, a non-SQL database, a knowledge graph, and a cache. Data ingestion is handled using a connectors library, while a Linked Data Event Stream (LDES) client provides data streaming capabilities.

The knowledge graph is an important element in this implementation. Apart from storing data, its underlying structure is based on an ontology that provides semantic interpretation of the data. Additionally, it links the data stored in the time-series database to the underlying ontology. Beyond the semantic layer, the knowledge graph also facilitates the cataloguing of data and assets.

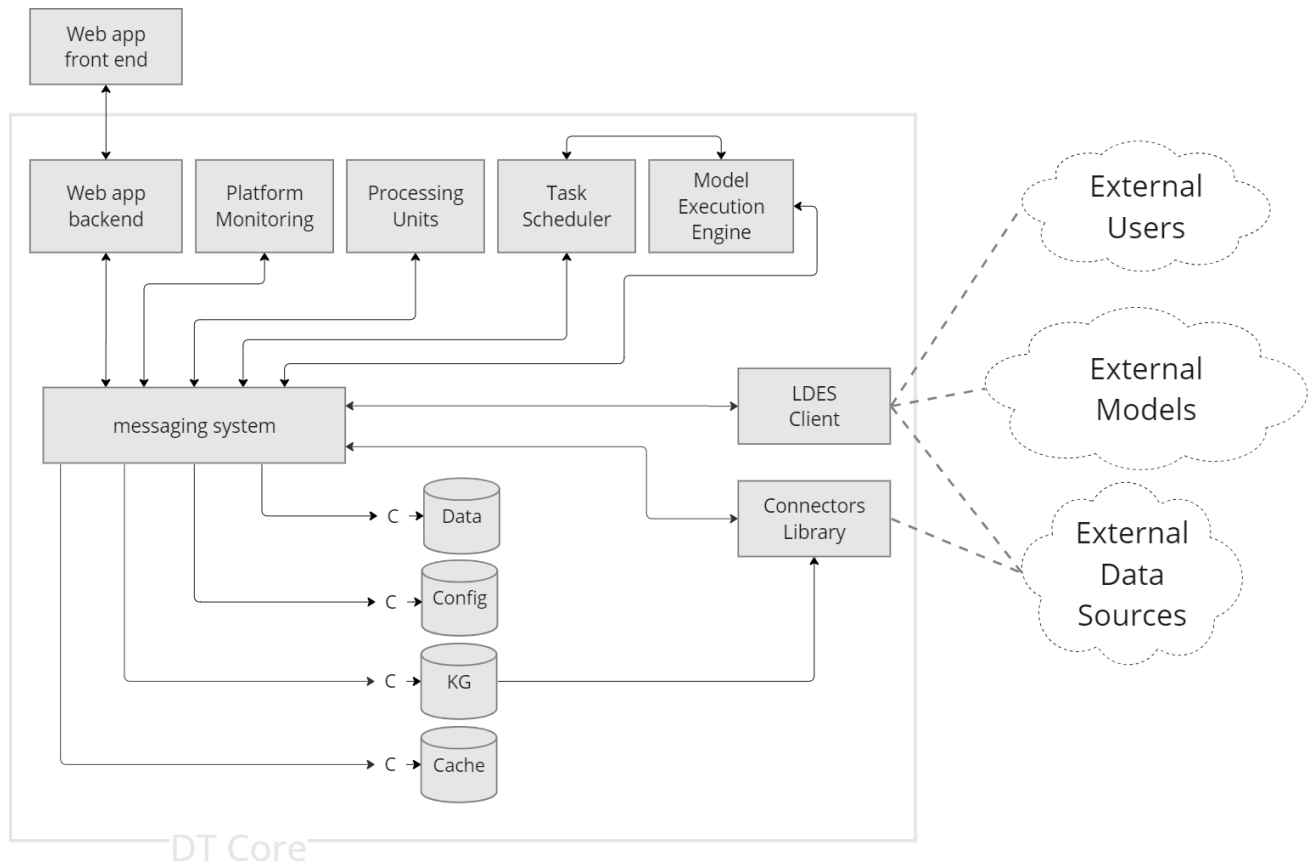


Figure 6: Operational Core of the Digital Twin for Dataspace Dynamics [19]

4 Digital Twin Architecture – Implementation & LL Update

Deliverable D3.6 [20] outlines the initial version of the Green Resilient IWT Digital Twin Generic application, focusing on identifying and describing models and tools for the Digital Twin. It includes diverse models addressing inland waterway transport resilience and sustainability, incorporating insights from previous projects. The importance of data availability is emphasized, introducing Data Spaces for seamless integration. The deliverable also details methodologies for identifying Key Performance Indicators and aligning Living Labs' needs with practical Digital Twin use cases. Ongoing model evolution and refinements based on data and user feedback are anticipated.

Building upon the conceptual architecture of the Digital Twin described in D3.1 [21], Deliverable D3.6 delves into its key components, including asset catalog (models, libraries, etc.), data, model integration with data sources, and use case descriptions.

In this latter deliverable, D3.6, various assets (models, libraries, etc.) were identified and described. These models, meeting the expectations outlined in D3.1 regarding functionality and ambition levels, are predominantly at level 4 of ambition,, thus focusing situational awareness, but also what-if simulations (more details in D3.1, Figure 2). This level enables simulation of the effects on resilience and environmental impact caused by specific events or choices, facilitating evidence-based decision-making among multiple options.

Each of these models serves different purposes, largely covering the functionalities of the components in the WP1 vision of DT components (see **Figure 7**).

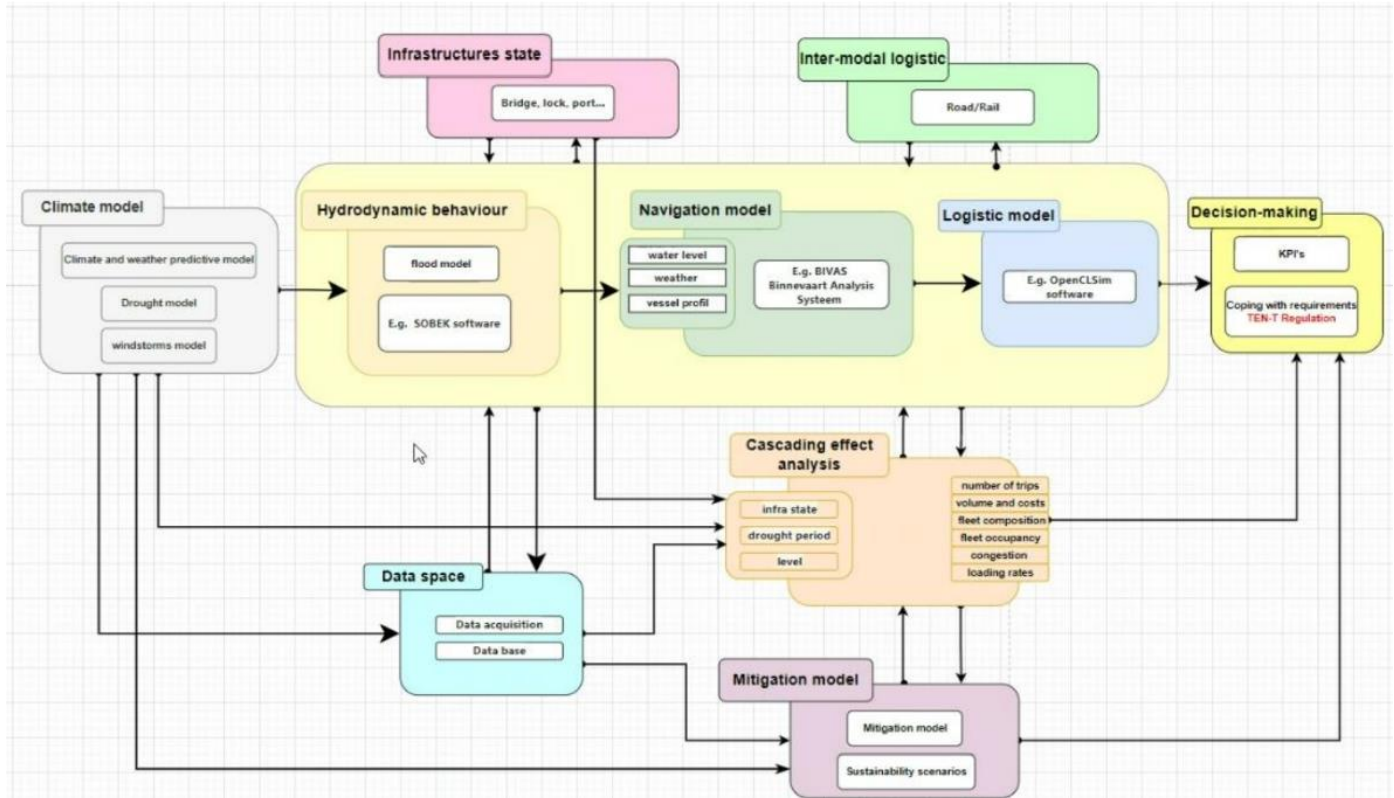


Figure 7: ReNEW WP1 vision of DT components. Source: IRTX as depicted in D3.6 [22]

Furthermore, each model is grounded in specific technology and exhibits varying levels of ambition, with a predominant presence of highly ambitious interactive models based on AnyLogic, Python, HUGIN, Protégé, Neo4j and EuRIS.

These models, either already in existence, set for further development, or expected to be developed during the course of the project, are listed below. A detailed description of each of these models can be found in Section 5 of deliverable D3.6 **Fehler! Verweisquelle konnte nicht gefunden werden..**

- IWT Simulation: virtual model to evaluate resilience in Inland Waterway Transport.
- Process Simulation: virtual model to evaluate resilience in autonomous operations.
- Bayesian Networks: probabilistic models to assess the impact on resilience and sustainable KPIs and also on the environmental variables.
- Knowledge Graph: graphical model to evaluate and predict the cascading effects of threat and vulnerability scenarios.
- Dynamic Routing: multi-criteria dynamic route planning of the vessel fleet.

Through these components, initial conceptualizations of model applications within each of the Living Labs (LLs) are explored in D3.6. As an example, **Figure 8** illustrates a test application of the IWT Simulation in LL2 (Douro River). Creating a virtual representation of the Douro River through the

utilization of multi-agent simulation techniques offers a dynamic and all-encompassing platform for modelling the intricate interactions within the IWT system. The simulation model is comprised of a sophisticated network of agents, each representing pivotal elements of the river's ecosystem, such as ports, locks, and diverse types of vessels and facilitates the exploration of a diverse array of scenarios, thereby providing valuable insights into the system's behaviour under varying conditions.



Figure 8: IWT Simulation application in Douro River. Source: ITAINNOVA.

The iterative process involved in Commencing the creation, development, or refinement of models is a dynamic and ongoing endeavour. with an initial design or prototype grounded in specific assumptions, the implementation specifics & details will evolve as additional information is gathered throughout the project. This information encompasses pertinent data and the specific requirements of the LLs, leading to the introduction of additional constraints and features. These constraints are instrumental in shaping and adjusting the models, progressively guiding them towards their ultimate iteration. Within this iterative paradigm, feedback and close collaboration with users, experts, and stakeholders from the LLs assume a pivotal role. Their insights and experiences are integral to refining the models, ensuring they precisely align with the needs and challenges encountered in various LL contexts.

5 Digital Twin Platform Architecture

The digital twin platform's objective is to support the deployment of the digital twins ensuring them access to the data they need to operate and allowing them to provide their output to the stakeholders in the Living Labs. For that, the digital twin platform offers compute, memory, and network resources to the hosted digital twin components. Additionally, high level services such as API management and authorization features are available.

The global architecture of the ReNEW digital twin platform is illustrated in **Figure 9** highlighting its key functional elements referred to as building blocks. It has been derived from the framework identifying the interacting entities, i.e. the digital twins, the data sources and the user applications, taking into account the stakeholders' and technical requirements.

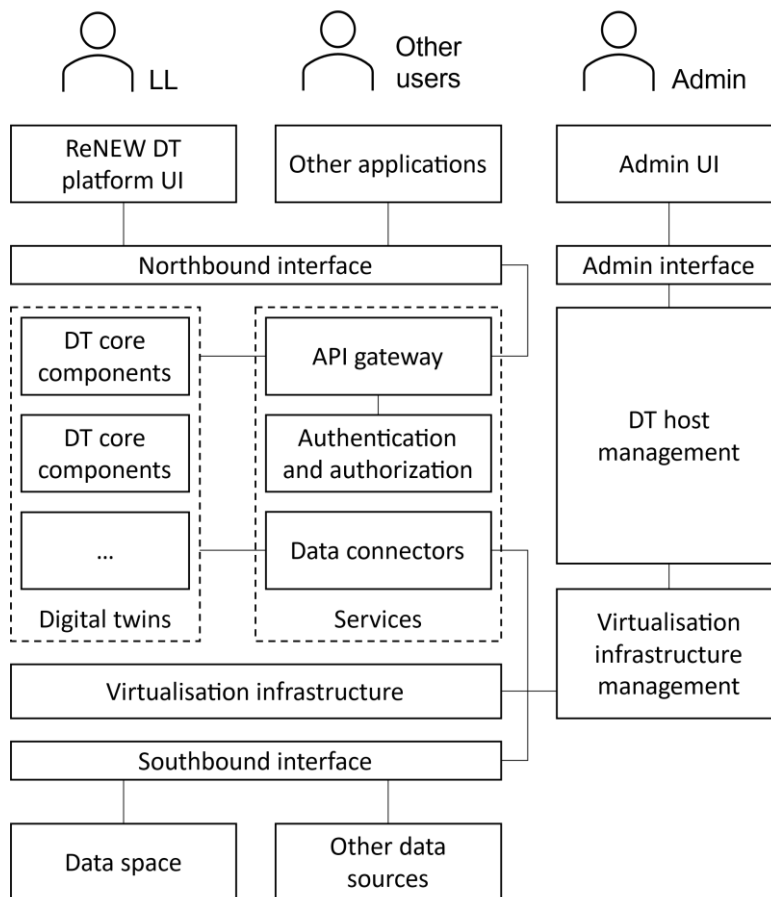


Figure 9: Digital twin platform architecture

The digital twins' perimeter regroups all the digital twin core components that are hosted thanks to a virtualisation infrastructure providing the required virtualized resources. The digital twin components do not directly interact with the outside world but rely on the platform's services instead.

The services provide high level functionalities supporting the interaction between the digital twins, the data sources and the final users. The data connectors constitute a bridge between the digital twins and the data sources including the ReNEW dataspace. They also act as data adaptors allowing the digital twins to access heterogenous data without implementing themselves all the required communication protocols. The API gateway acts as a single entry-point for the requests coming from the user applications to obtain the insights from the digital twins. It hides the potential heterogeneity of the API exposed by the digital twin back-ends facilitating updates and maintenance. It also provides data protection mechanisms by managing security implementation regarding external communication with the support of the authentication and authorization building block. The latter ensures that only authenticated and authorized users and applications are allowed to access the digital twin's output.

The digital twin platform presents two interfaces for the digital twins to interact with the other entities. The northbound interface is destined to the user-facing applications that rely on the output of the digital twins in their operations. Example of such application is the ReNEW user interface that could be implemented as a dashboard to visualize insights from the digital twins. The southbound interface allows the hosted digital twins to interact with the data sources in particular the ReNEW dataspace.

The digital twin platform's management consists in the provision and monitoring of the virtualized resources and the configuration of the services according to the needs from the digital twins through a dedicated admin user interface.

The deployment of digital twins on the platform requires continuous collaboration between the developers and the platform administrator. The first provides the technical requirements allowing the second to instantiate and configure the necessary virtualized resources. Then the developers deploy the packages onto the virtual hosts. Afterwards, the platform admin performs the necessary configuration on the services to take into consideration the newly deployed components. Finally, tests are conducted to ensure successful integration before indicating to the stakeholders the availability of the corresponding digital twin.

In summary, the digital twin platform not only hosts the digital twins' components but ensures they are interfaced with the ReNEW dataspace or any other data sources and the user-facing applications. Details regarding the requirements, the architecture and the implementation are available in the dedicated deliverable D3.9 – Generic applications deployment to the Living Labs V2 [24].

6 A Common Denominator for the Living Labs

The work carried out in WP1 lays the foundation for establishing a common denominator across all living labs. Specifically, Deliverable 1.1 [25] and Deliverable 1.8 **Fehler! Verweisquelle konnte nicht gefunden werden.** provide a comprehensive discussion on defining a framework for resilient and sustainable Inland Waterway Transportation (IWT) systems within the ReNEW project context. The methodology for resilience and sustainability, outlined in these documents, identifies common barriers and specific challenges across the living labs (LLs). These challenges are then mapped to Resilience and Sustainability indicators and Key Performance Indicators (KPIs), creating a foundation for assessing current or anticipated interventions. This assessment is further supported by a decision-support system for the digital solution of a resilient and sustainable IWT system.

Throughout this analysis, certain recurring aspects come to light. These include the (re-)planning of vessel trips with real-time adjustments in case of disruptions, achieving synchro-modality in various transportation hubs, analysing current and future modalities in terms of efficiency, resilience, and environmental impact, as well as assessing infrastructure resource optimization. These recurring themes serve as a starting point, guiding the application of architectural principles and frameworks to develop common use cases across the living labs. The ultimate aim is to align with common goals through the implementation of the framework architecture for a Data Space and a Digital Twin.

6.1 Navigability for Inland Waterway Transportation

Navigability in inland waterway transportation refers to the suitability of a body of water, such as a river, canal, or lake, for the safe passage of water vessels, including boats & ships. A waterway is considered navigable if it possesses adequate depth, width, and tranquillity, minimizing obstructions such as rocks, reefs, or trees. Additionally, bridges spanning these waterways must provide sufficient clearance, and high flow speeds may render a channel unnavigable due to the risk of ship collisions. Unfavourable conditions, such as ice formation in winter or in high-latitude regions, can also impede navigability.

Furthermore, navigability is context-dependent; a smaller river may accommodate smaller craft like motorboats or kayaks but may pose challenges for larger freighters or cruise ships. The enhancement of navigability in shallow rivers may involve the installation of locks to regulate flow and increase upstream water levels or dredging to deepen the stream bed.

Various threats and hazards can impede navigability. An extensive classification of threats and hazards can be found in the “D 1.1. Resilience and Sustainability analysis in IWT and strategic development Baseline Building Blocks” [27]. Amongst these threats we find Natural Phenomenon Disruption Events significantly impacting the navigability of waterways for various vessels, of which floods, high waters and low waters are some of the more prevalent hazards. Visibility issues, exacerbated by climate change-induced phenomena such as increased fog, rainfall, or haze, can

further complicate navigation. Changes in water levels, ranging from excessively shallow to excessively high, pose challenges such as hull scraping or bridge clearance issues. Water shortages may also inhibit the use of locks due to the scarcity of usable water.

In order to enhance the resilience of the entire system, it is crucial to consider these effects when planning routes or voyages. Additionally, conducting scenario analyses would facilitate more deliberate and well-thought-out infrastructure changes.

Proposal for a common use case: Navigability Planning

6.1.1 The proposed common use case of 'Navigability Planning' aims to address these challenges. Users would input a route (origin to destination) and various vessel parameters, including length, width, draught, hull shape, height, and average cruising speed, along with cargo details such as tonnage and type. Additional parameters, such as water level fluctuations due to floods or heatwaves, can also be incorporated. The outcome of this process would be a feasibility check on a specific route, providing information on the navigability status of the vessel between the given origin and destination. This analysis would consider factors such as lock and bridge clearances, riverbed depths, ship propulsion characteristics, desired time of travel and other pertinent variables.

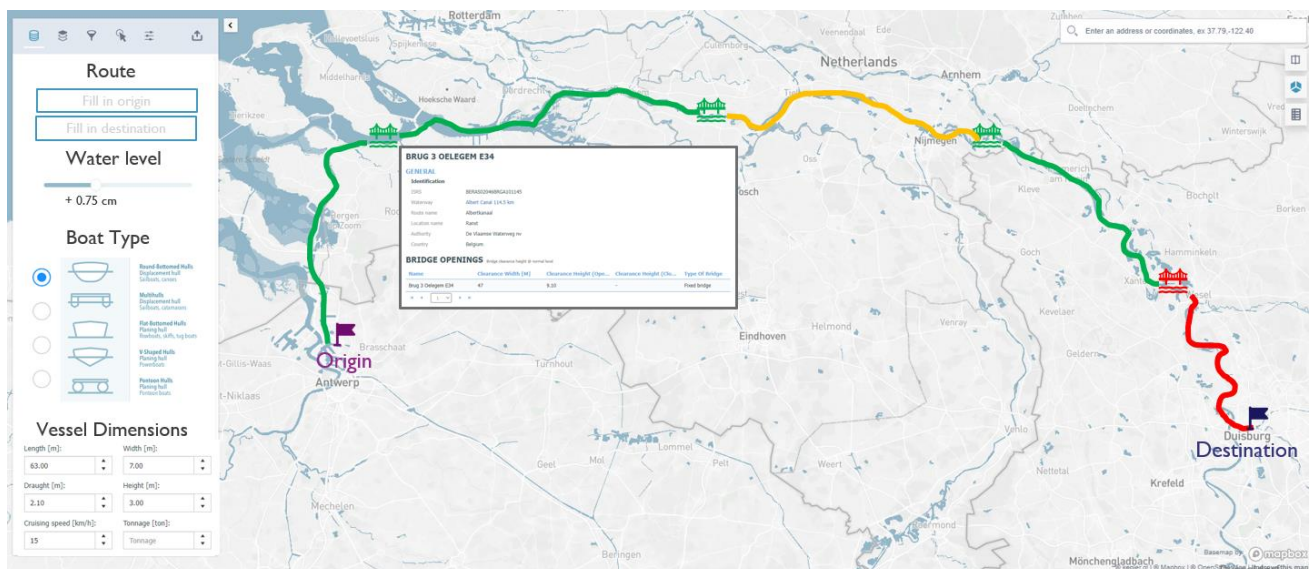


Figure 10: Mock-up / design of a possible UI for common use case 1 about navigability planning

Evaluating Inland Waterway Transportation: Beyond Navigability

6.2 In delving into the realm of Inland Waterway Transportation (IWT), an integral facet to consider lies in exploring the array of alternative transport modes available and conducting a comprehensive comparative analysis across diverse parameters benchmarking sustainability and resilience KPIs. This extends not only to within IWT, where one might compare various vessel sizes or hull types, but also encompasses a broader spectrum, comparing IWT with alternative transport modes such as truck, rail transport, or emerging technologies like autonomous barges.

The selection of a specific transportation modality significantly impacts the efficiency and sustainability of the supply chain. When evaluating alternatives across different modalities, considerations extend beyond mere speed, incorporating nuanced factors such as environmental impact, noise generation, and susceptibility to disruptions like traffic congestion.

To facilitate a comprehensive analysis of these alternatives, we advocate for the implementation of a modality comparison, constituting a second common use case. Similar to the navigability planning proposed earlier, users would input origin-destination pairs, but this time, the focus shifts to a comparative assessment of various transportation modalities. Key Performance Indicators (KPIs) would be diverse, encompassing metrics such as duration, average speed, waiting time, confidence intervals on Estimated Time of Arrival (ETA), as well as environmental factors like CO₂ or NO_x emissions, noise levels, and overall cost considerations.

6.2.1 By undertaking such an in-depth analysis, stakeholders gain insights into the competitiveness of specific modalities on particular routes. This comprehensive evaluation not only aids in optimizing route selections but also allows for informed decision-making regarding the most suitable transportation modality based on the specific requirements and priorities of the supply chain.

Proposal for a second common use case: Modality Comparison for Informed Decision-Making

The proposed modality comparison use case serves as a decision support system, offering stakeholders the ability to make nuanced choices based on a thorough understanding of each modality's performance characteristics. The inclusion of environmental metrics aligns with sustainability goals, providing a holistic view of the ecological footprint associated with each transportation option.

This comparative analysis could further extend to dynamic scenarios in the future, accounting for varying conditions such as weather, traffic patterns, or infrastructure changes. Or even more so by integrating real-time data and scenario-based simulations, this could become a dynamic resource for strategic planning, enabling stakeholders to adapt and optimize transportation choices in response to evolving circumstances.

In conclusion, this would not only streamline decision-making processes but also contribute to the overarching goal of creating resilient and sustainable transportation networks, aligning with the broader objectives of environmentally conscious and efficient supply chain management.

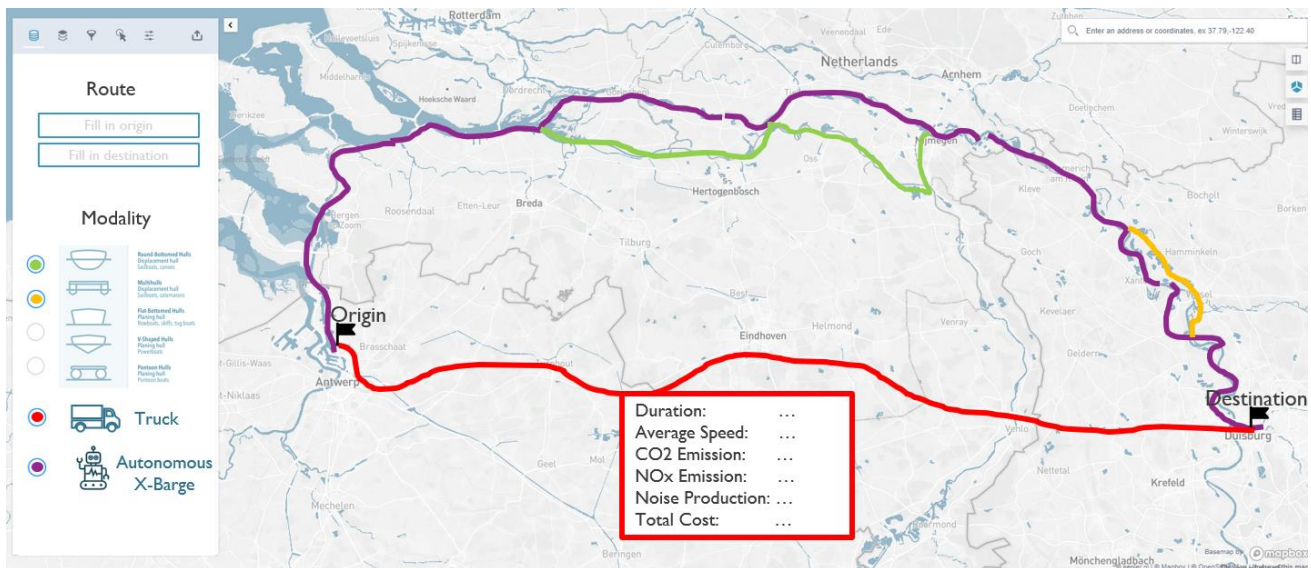


Figure 11: Mock-up / design of a possible UI for common use case 2 about modality comparison

7 Leveraging the Available Building Blocks of Architecture, Other Work Packages & LLs

Alignment with the other Work Packages within the project

7.1 Technical Architecture and the proposed common use cases

The overarching technical architecture is centred around the deployment of Open Local Digital Twins. Each party involved exposes a dataspace connector, thereby enhancing the capabilities of the Digital Twin deployment. This extension introduces significant value through aspects such as data discovery, data usage policies, sovereign identity management, and increased interoperability. These concepts could be mapped to the 2 proposed common use cases. Thus, realizing the proposed system setup in the general reference architecture.

Within this framework, the use cases involve a digital twin ecosystem of the IWT & the transport network, which could utilize the dataspace connectors to share critical data related to navigability, including vessel specifications, cargo details, environmental factors or data about the infrastructure (such as bridges, locks & riverbeds). The connector, in this context, would facilitate the discovery & integration of relevant and potentially interesting data sources for navigability planning. It acts as a trust mechanism, allowing seamless and secure data exchange between digital twins and third-party sources. This ensures that valuable navigational insights can be obtained without compromising data security or integrity and ensuring interoperability & a 'split-of-concerns' between different actors.

Alignment with the T1.2 knowledge graph & probabilistic models

Task 1.2 within work package 1 is dedicated to crafting an Ontology and Knowledge Graph (KG). Unlike a mere compilation of data, this KG constitutes a system meticulously constructed to standardize resilience concepts in Inland Water Transport (IWT) and its associated infrastructures and operations and the relations they have to each other. Once fully implemented, the KG can facilitate a spectrum of analyses, ranging from risk and cascading effect assessments to evaluations and optimizations in cost and efficiency. It serves as a foundational element, adept at delivering accurate and efficient outcomes amidst diverse operational and environmental conditions, thereby aligning seamlessly with both the technical architecture and the proposed common use cases.

Given that existing ontologies in the domain either lacked compatibility with project objectives or failed to encompass all necessary aspects, the creation of a fit-for-purpose ontology was imperative. The ontology, currently in its early stages as developed under Task 1.2 and as described in deliverable D1.4 [27], plays a pivotal role in enabling desired functionalities within the ReNEW project. Despite its nascent form, it is designed to be extensible and adaptable, paving the way for future updates and

refinements in alignment with the evolving use cases. The KG, shall serve as a central component to model the data & the intermediary relations between different nodes, required to fulfil both use cases & realize the practical implementation of the reference architecture.

Secondly, it can be considered to include a link to the probabilistic models being developed in WP1. The link with the knowledge graph is more obvious, feasible and imperative. However, depending on the evolution of the implementation and the emerging requirements, it could be conceptualized to integrate a link to the Bayesian models as well. By using the same setup of the knowledge graph, interoperability and a possible future extension are guaranteed.

Current and future alignment with the Living Labs

7.2 The proposed reference architecture outlined in deliverable D3.1, coupled with the foundational building blocks from WP1, establishes the groundwork for our endeavours. It serves as the conceptual scaffold, providing a starting point for the implementation phase. The Living Labs, in turn, contribute invaluable concrete requirements and intricate details crucial for effective execution.

In practical terms, the acquisition of specific data pertaining to Inland Water Transport (IWT) infrastructure—comprising waterway layout, bridges, locks, and more—is orchestrated through integrations with diverse sources. For instance, a direct link to the data platform of APDL facilitates access to intricate details concerning the Douro area. Additionally, collaborations with various segments of EuRIS furnish details crucial to the other Living Labs' areas of focus.

Within the context of Living Lab 3, a notable intersection occurs in the route planner, serving as a linchpin for powering common use cases. This functionality not only fuels navigability calculations but also potentially contributes to facets of modality comparison. All these efforts align seamlessly with the envisioned knowledge graph of Task 1.2, ensuring maximal interoperability and commonality across the Living Labs.

Furthermore, Living Labs 1, 2, and 4 emerge as rich repositories of specific details and data concerning vessels and barges. These details form the bedrock for the execution of simulations and scenarios integral to the common use cases. Examples include dimensions of the Floating Modular Platform (FMP) from LL1, specifications of autonomous barges in LL4, or particulars about vessels active on the Douro River in LL2. This nuanced data serves as specific input for executing scenarios such as a modality comparison, evaluating how an autonomous barge performs compared to traditional modalities in terms of different Key Performance Indicators (KPIs). Additionally, it allows for a comprehensive understanding of the impact of factors like water-level rise on the fleet navigating the Douro River.

In essence, the integration of Living Labs data into the broader framework ensures not only the practicality of executing common use cases but also enriches the depth and applicability of the entire system. The Living Labs, by contributing detailed insights and domain-specific data, play a pivotal role in aligning practical implementation with the overarching objectives of the project.

Relationship between Common denominator use cases and Living Lab requirements

Within the context of the ReNEW project, several scoping workshops with Living Lab stakeholders have been conducted to translate Living Lab Data Space and Digital Twin requirements into implementable Living Lab user stories. These user stories served as a basis for comparison amongst the Living Labs to constitute the common denominator use cases of Navigability Planning and Modality Comparison for informed Decision Making as described above (see 6.1.1 and 6.2.1).

In what follows we give a brief overview on the related User Stories which have been given (very) high priority by the Living Lab Owners.

Living Lab 1: Multimodal city logistics hub

Living Lab 1 has a clear KPI on assuring navigability for inland waterways during extreme weather events as described elaborately in D 4.6 [29] referring to water bombs (causing high water).

Its Smart Terminal use case wants to increase the resilience of the Terminal by setting up a Mobile Control Center. The Digital Twin will assist in ensuring situational awareness of the resources at the terminal on the condition that they provide data that can be connected to the digital twin.

Relation to User Stories: the proposed use cases were chosen as a common denominator of the Living Labs as they contribute to the overall validated user stories by Living Lab 1.:

Epic	User Story
General Setup	As an administrator I want to have basic user management so only people with the right login can access the app
General Setup	As a user I want to have a map overview of the Ghent area with basic map controls (zoom, pan, 3D-toggle, street names, search)
Environment status	As a user I want to view information on the height of the water level
Environment	As a user I want to view the vessels carbon foot print
Waterway	As user I want to view bridges critical clearance
Waterway	As user I want to view a heat map of fairway channel depth
Disruption	As user I want to be warned about the occurring disruption (infrastructure, accident, etc)
Waterway	As a user I want to view hydraulic map (depth, width, flow, flood area)

The bulk of the User Stories that are not being taken into account by the common denominator use cases are either Living Lab specific (no link to other Living Labs) or lack data availability in the current phase of the project.

Epic	User Story
Floating Modular Platform	As a user I want to track the positioning of the FMP + its 2 vessels on the map in (nearly) real-time
Battery Tab	As a user I want to view the current battery level of the FMP battery pack in a separate battery tab of the FMP-pop-up
Sensor Dashboard Tab	As a user I want to view the last 24h of all sensor readings per split pollutant as a line chart in a separate sensor tab of the FMP-pop-up
Smart City Terminal	As a user I want to view a pop-up with detailed info from the SCT upon clicking on the building (SCT-Pop-up)
Remote Controlled Crane	As a user I want to view a pop-up with detailed info from the crane upon clicking on the building (crane-pop-up)
Remote Controlled Crane	As a user I want to view whether the crane is currently being operated in the crane-pop-up as a green/red light
Remote Controlled Crane	As a user I want to view other relevant metadata in the crane-pop-up
Remote Controlled Crane	As a user I want to click on a button in the crane-pop-up that redirects me to the remote control environment of the crane (external website)
Drone	As a user I want to be able to track the location of the remote controlled drone
Drone	As a user I want to view a pop-up with detail from the drone upon clicking on the drone (drone-pop-up)
Drone	As a user I want to click on a button in the drone-pop-up that redirects me to the remote control environment of the drone (external website)
Inbound Logistics	As a user I want to track the positioning of incoming vessels, coming to drop off goods at the SCT in (nearly) real-time
Inbound Logistics	As a user I want to view a pop-up with detail from incoming vessel upon clicking on the drone
Inbound Logistics	As a user I want to see whether vessels are platooning & if so, which vessels are grouped together (with their respective data in a popup)
Environment status	As a user I want to view information on the water quality/air quality
Battery Tab	As user I want to view health status of the battery (remaining useful life)
Battery Tab	As user I want to view whether the battery is not engaged
Smart City Terminal	As a user I want to view the remaining battery capacity, connecting with Energy Management System (EMS) of the battery pack
Smart City Terminal	As a user I want to view the availability of energy (energy pack for external use)
Smart City Terminal	As user I want to view the remaining storage capacity
Smart City Terminal	As user I want to view the position of waste reception/retour logistics
Remote Controlled Crane	As user I want to view the loading and unloading capacity of the crane
Remote Controlled Crane	As user I want to view the estimated waiting time
Remote Controlled Crane	As user I want to view the estimated transit time
Disruption	As user I want to view the position of the maintenance operation (river bed, infrastructure, etc)
Disruption	As user I want to view a map of rerouting solutions
Environment	As a user I want to view noise and air pollution rate
Simulation	As user I want to simulate disruption scenario/prediction model
Simulation	As user I want to simulate hydraulic and climate behavior according to a setted scenario in order to assess the navigabilité

The latter issue could be dealt with throughout the project on the precondition that the data becomes available in a way that it can be ingested into the Data Space and the Digital Twin. Depending on the timeline and implementation roadmap, the Digital Twin functionalities can be extended with these user stories.

Living Lab 2: Douro River

An important KPI for Living Lab 2 refers to Navigability During Extreme Weather Events. This KPI will measure “the capacity of the Douro River to facilitate safe and efficient inland navigation despite the occurrence of major floods/flash floods or droughts. It quantifies the river's ability to maintain a certain percentage of navigable capacity during such extreme weather conditions” [30].

The common denominator use cases relate strongly to the following user stories that were extracted from the workshop with the stakeholders of Living Lab 2:

Epic	User Story
Water Levels	As a user I want to visualise the locations where water level measurements happen as dots on a map
Water Levels	As a user I want to visualise the current water levels (in real time) by colouring the various locations (e.g. dark blue = high, red = low)
Water Levels	As a user I want to visualise the historical water levels of a measuring location in a pop-up & as linechart, upon clicking on a certain location
Scenario Builder	As a user I want to manually input hypothetical water levels at certain locations as input to the model
Scenario Builder	As a user I want to save these hypothetical parameters as a scenario & give it a name
AIS Positioning	As a user I want to see the historical positions of vessels on the Douro river
Navigability	As a user I want to view the continuity of path according to vessel classes
Navigability	As user I want to view recommendations about the suitable vessel classe according to the waterway status (water level, width, flux, etc) or par section

Following user stories are not taken into account in the common denominator user cases as we lack the data or as they are very Living Lab specific. Depending on the timeline and implementation roadmap, the Digital Twin functionalities can be extended with these user stories.

Epic	User Story
Waste Water Levels	As a user I want to see a decrease in waste water levels of a selected barge on a map (the location of the waste water decrease)
Weather Forecast	As a user I want to visualise the weather stations on a map
Weather Forecast	As a user I want to visualise the current weather on a map
Weather Forecast	As a user I want to visualise the weather forecast for the upcoming 3h on a map (+ 6h + 24h)
Flooding Model	As a user I want to visualise the results of the flooding model (for the current time) on a map & highlight zones that have high flooding risks
Flooding Model	As a user I want to visualise the results of the flooding model (for the coming 3h) on a map & highlight zones that have high flooding risks
Scenario Builder	As a user I want to run the flooding model with a created scenario & visualize the result on the map
Simulation	As user I want to simulate hydraulic and climate behavior according to a settled scenario in order to assess the navigability
Simulation	As user I want to simulate disruption scenario
Vessel behavior	As user I want to view the compliance of selected vessel with environmental requirement

Living Lab 4: Autonomous Zero Emission Barge

As described in D4.15 [31], Living Lab 4 aims to demonstrate enhanced navigability of the autonomous X-Barge, a newly designed and constructed CEMT class 4 barge with a significantly lower environmental footprint and with a design more suitable for sailing in low or high water level conditions.

By including vessel characteristics in addressing navigability under specific high or low water conditions, the common denominator use cases clearly contribute to the LL4 goal. Moreover, the modality comparison for informed decision making use case will allow the X-barge to be compared to other vessels and transport modes in terms of sustainability and resilience KPIs.

Relation to User Stories: the proposed use cases were chosen as a common denominator of the Living Labs as they contribute to the overall validated user stories by Living Lab 4:

Epic	User Story
Map view	As a user I want to visualise the origin-destination on a map
Map view	As a user I want to see bridges, locks and terminals on the corridor on a map
Vessel view	As a user I want to view the actual location of the vessel on a map
Vessel view	As a user I want to know vessel draft (maximum depth), length and width and aircraft
Corridor information	As a user I want to know the infrastructure status on the corridor (locks operating / bridges opening times etc.)
Corridor information	As a user I want to know the river status on the corridor (water level / velocity / ...)
Emissions calculator	As a user I want to be able to see the CO2 saved in comparison with a vessel using diesel (traditional), ammonia, methanol, ...also on per TEU or per ton basis
Cargo status	As a user I want to know the the cargo capacity of the vessel (capacity space left / taken on the vessel)
Cargo status	As a user I want to know the the cargo weight of the vessel (cargo weight taken / available on the vessel)
Map view	As a user I want to visualise the optimal route between origin-destination on a map (2 routes: Rijn-Schelde or Gent-> Terneuzen->)

Not yet integrated in the common denominator use cases but entered in the backlog and assessed over time in terms of prioritization, are the following user stories. As with the not-addressed user stories of other Living Labs, integration will depend on the timely availability of required data sources as well as available remaining budget for implementation.

Epic	User Story
Map view	As a user I want to visualise the optimal route between vessel and potential charging station(s) on a map
ETA	As a user I want to get an ETA at the destination
ETA	As a user I want to get an ETA at the intermediate infrastrcutrures (bridges, locks, terminals)
Vessel view	As a user I want to visualise the energy being consumed
Vessel view	As a user I want to visualise the enegy still available by the X-barge
Energy simulation	As a user I want to simulate the energy usage on the route
	As a user, I want to be able to see previous trips made by the X-Barge and its details (historic data viz)
Battery providers (bunke	As a battery provider : View on the incoming vessel (ETA) and its energy requirement
Loading plan	As a user I want to know the loading plan ((terminal communicates containers that will be loaded -> operating center of the vessel -> define stowing plan.
Vessel view	As an user I want to know the actual and expected communication coverage available along the route sailed for the different comms used
Regulatory	Agreement with the waterway authorities for autonomous operation is agreed

8 Conclusion

In navigating the complex waters of Inland Waterway Transportation (IWT), the proposed common use cases of 'Navigability Planning' and 'Modality Comparison' emerge as integral pillars within the broader scope of the ReNEW project. These use cases, designed to address challenges in the IWT domain, present a comprehensive approach to decision support and optimization, grounded in cutting-edge technological solutions of our work package.

The first use case, 'Navigability Planning,' delves into the intricacies of ensuring smooth vessel navigation between specified origins and destinations. Users are equipped with a decision support system to conduct a feasibility check, considering factors such as lock and bridge clearances, riverbed depths, and even unexpected variables like water level fluctuations due to floods or heatwaves. This use case not only enhances the efficiency of route planning but also fosters a deeper understanding of the navigability status along the waterways and their infrastructure.

Complementing the Navigability Planning use case is the second common use case, 'Modality Comparison for Informed Decision-Making.' This feature offers stakeholders a method to compare various transportation modalities, extending beyond IWT to encompass truck, rail transport, and emerging technologies like autonomous barges. Users can assess the transportation network on various indicators (KPIs) such as duration, average speed, environmental impact, noise levels, and overall cost considerations. The inclusion of environmental metrics aligns seamlessly with sustainability goals, contributing to the overarching objective of creating resilient and eco-conscious transportation networks.

Crucial to the successful implementation of these use cases is the alignment with the project's technical architecture and other work packages. The deployment of open local digital twins, coupled with dataspace connectors & technologies, serves as a linchpin, enabling seamless and secure data exchange between digital twins and third-party sources. The knowledge graph amongst others, developed in parallel in WP1, emerges as a foundational element, standardizing resilience concepts and facilitating diverse analyses from risk assessments to cost optimizations.

Furthermore, the integration of Living Labs data into the broader framework ensures not only the practicality of executing common use cases but also enriches the depth and applicability of the entire system. Living Labs 1, 2, and 4 contribute invaluable insights and domain-specific data, aligning practical implementation with the overarching objectives of the project. Noteworthy is the acknowledgement of specific user stories and priorities from each Living Lab, showcasing a commitment to addressing real-world challenges and aligning the project's goals with the needs of stakeholders.

As the ReNEW project progresses, the proposed use cases stand poised to impact decision-making processes in IWT. The potential for future integration of additional user stories, contingent on data availability and project timeline considerations, ensures the adaptability and scalability of the system.

In essence, these common use cases pave the way for a resilient, sustainable, and technologically advanced future for Inland Waterway Transportation.

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