MAGPIE

SMART GREEN PORTS

Digital Platforms & Services for Port Operations

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Abbreviations and Acronyms

API	Application Programming Interface
APS	Ports of Sines and Algarve Authority
ARA	Amsterdam, Rotterdam, and Antwerp seaports
BESS	Battery Energy Storage Systems
CMS	Cable Management System
CO_2	Carbon Dioxide
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
DT	Digital Twin
EC	European Commission
EDPS	Event-Driven Process Stimulator
EGD	European Green Deal
EU	European Union
EDF	Électricité de France
EDIFACT	Eletronic Data Interchange for Administration, Commerce and Transport
EGD	European Green Deal
EMS	Energy Management System
ETA	Estimated Time of Arrival
GHG	Greenhouse gas
GIS	Geographical Information System
IDS-RAM	International Data Spaces Reference Architecture Manual
IoT	Internet of Things
ITF	International Transport Forum
LNG	Liquid Natural Gas
REEFER	Refrigerated container
RES	Renewable Energy Sources
SME	Small and Medium Enterprise
OPS	Onshore Power Supply
OWL	Web Ontology Language
PCS	Port Community Systems
PoR	Port of Rotterdam

TEU	Twenty-foot Equivalent Units
TMS	Terminal Management System
TOS	Terminal Operating System
UAV	Unmanned Aerial Vehicle
UC	Use Cases
UI/UX	User Interface / User Experience
ZAL	Zona de Atividade Logística (Logistics Activities Zone)
ZES	Zero Emission Service
ZIL	Zona Industrial Logística (Industrial Logistics Zone)

Executive Summary

Ports will play a major role in boosting the use of cleaner technologies, green energy carriers and logistics concepts in maritime transport, port operations and hinterland transport to reduce Greenhouse gas (GHG) emissions. The objective of WP4 is to develop and to integrate modular, flexible, and interoperable digital tools. Such digital tools will be applied to various infrastructures and assets of ports, allowing for data collection, system modelling, data handling, intelligence, decision support capabilities, and GHG emissions reductions and air quality improvements. More specifically, WP4 aims to (i) identify requirements and existing platforms, systems, and other sources of data; (ii) to define a modular architecture; (iii) to implement interoperable digital representations of the (non-)physical assets of ports; and implement the components that form the foundation for a Digital Twin (DT) for ports.

This deliverable reports on the work carried out within Task 4.1 of WP4, which included the following stages:

1. Characterisation of participant ports, aiming to provide subsequent tasks, in particular tasks T4.2 and T4.3, with a better understanding about the operational context and organisational aspects of each port, its actors, and their responsibilities within port ecosystems. This characterisation incorporates the typology of ports proposed in WP9.
2. Given the orientation towards fostering decarbonisation and optimising operations and energy consumption, a survey of existing and future digital platforms and related projects was carried out for each participant port.
3. In accordance with an Enterprise Architecture approach, a mapping between port assets and digital platforms was established to identify digitalisation gaps that relate to the double transition effect and hinder the implementation of more sustainable, optimal operations within and outside ports.
4. Definition of the conceptual systems architecture of a Digital Twin for ports, to support several use cases related to the digital tools of WP4, and the demonstrators of MAGPIE.
5. Description of the use cases with various levels of granularity according to their maturity level and work progress of other tasks and demonstrators within MAGPIE. In tasks T4.2 and T4.3, the identified use cases will be further developed (e.g., demo related use cases are still under development), revisited, refined, and materialised into the components that form the DT for ports.
6. The preliminary identification of the ports (and hinterland) assets to model and characterization of data needs and flows that will feed the development of the semantic model at the foundation of the DT architecture and the digital tools.

Characterization of MAGPIE Ports

The inventory and characterization of ongoing, or past, projects related to the MAGPIE topics, is meant to contribute to the identification of available data and tools that are relevant to the development of the digital twin and tools. The existing and planned projects within PoR, HAROPA PORT, DeltaPort and Sines already allow for some interaction between port actors supporting information exchange for optimising operations and, in some cases, the implementation of tools that will allow decision making and planning based on environmental factors, in addition to the current mainly logistics focus. Several ports are

implementing projects supporting the integration of local renewable electricity generation, introduction of new energy vectors, for example hydrogen, onshore power supply and electricity charging infrastructure.

The MAGPIE ports were characterised regarding their port model, and the main actors that form the port ecosystems. The landlord port model is prevalent across port authorities. Port terminals and other actors usually operate on a concession basis. Such a port model is prone to limited visibility of the information flows across the actors involved in operational processes, yielding inefficiencies in port operations that corroborate increased GHG emissions and energy consumption levels. Most of the existing digital platforms are not oriented towards supporting decarbonisation and reduced energy consumption, and work as a data hub, in which data are mostly provided through human input. Furthermore, real-time data about emissions levels and energy consumption are either unavailable, or not yet duly exploited, which justify the relevance of the digital tools that will be developed within MAGPIE (WP4).

Definition of the conceptual model for the DT

The myriad of digital tools within the ports' ecosystems – often proprietary – yield data that conforms to different specifications, heterogeneous by nature, which may be difficult to integrate and reason upon. Moreover, there is a challenge within MAGPIE to ensure that actors provide (part of) the data they have available to support the digital tools, while ensuring security and data sovereignty. A conceptual systems architecture based on a data spaces approach was defined for developing the components of a Digital Twin for ports. Actors of the port ecosystem will be able to interact with the functionalities of the DT by means of a graphical user interface frontend that orchestrates the interfaces of digital tools, including the visual representation of the outputs that they provide, e.g., by means of interactive dashboards. An ontology, i.e., a semantic model, will be developed within WP4 to support the integration of heterogeneous data from multiple sources. Such an ontology will build upon the domain knowledge retrieved from the use cases and ongoing discussions with domain experts that relate to the actors of port ecosystems.

Identification of preliminary requirements for the DT and digital tools

The main Use Cases (UC) that are being developed as part of tasks T4.1, 4,2 and 4.3 support the definition of the requirements and development of the digital twin and tools. The use cases cover a range of instances that represent the way the DT and the digital tools will be used by the ports' stakeholders at different levels of implementation. Firstly, UCs that represent the potential use of the DT/tools at a higher level of operation, spanning one or several terminals, and eventually the full ecosystem of ports. Secondly, the use of the digital tools within various scopes and the expected links to the DT. And third, to represent the use of the digital twin and tools at the level of the MAGPIE demos. The description of the use cases is still ongoing, but an initial identification of the data needs and flows, and the main assets to model have already been identified for 5 distinct cases at the level of the port ecosystem and the digital tools. The description of the use cases for demonstrators only started in M12, hence it is still not presented herein, and it is expected to last until the end of M20. Thus, the refinement and further development of the use cases will take place as part of the activities in tasks T4.2, T4.3 and T4.4.

Relationship to other WPs and tasks

Task T4.1 supports the development of the other tasks in WP4 – by characterising the context of analysis, the actors which can contribute towards providing the domain knowledge required to set up the preliminary requirements of the digital twin and tools to be further conceptualized and developed in the remaining tasks in WP4. Task T4.1 also included in principle development of use cases related to demos, and particularly, demos 6, 9 and 10 of WP5 and WP6, and interaction with activities taking place in WP8 – identifications of KPIs, the development of the Master Plan in WP9, through the possible contributions of the digitalization of ports and development of dedicated digital tools to the decarbonization pathways, and, finally, with WP10 in the exchange of practices and exploration of synergies with other sister projects in terms of the contribution of digitalisation of ports to the decarbonizations of its operations.

1 Introduction

In 2019, the European Commission (EC) launched the European Green Deal (EGD)[1] strategy that sets out the background and support for a sustained reduction of GHG emissions for the EU-27 in line with the climate mitigation goal of keeping global warming well below 2°C. The current targets include 55% GHG emissions reduction by 2030 and carbon neutrality in 2050. Greening transport is one of the key objectives of the EGD as the sector accounts for 25% of the EU's GHG emissions[2]. Accordingly, the objective for the transport sector is a reduction in emissions of 90% by 2050. The roadmap for the sector is further detailed in the Sustainable and Smart Mobility Strategy[3] that was published in December 2020. Within the strategy, ports take on a leading role in the decarbonisation of different modes of transport, and as a hub and enabler of low carbon energy vectors supply chains.

1.1 Context and objectives

Seaports and Inland ports will play a major role in boosting the use of cleaner technologies, green energy carriers and logistics concepts in maritime transport, port operations and hinterland transport to reduce GHG emissions. The objective of WP4 is to develop and to integrate modular, flexible, and interoperable digital tools. Such digital tools will be applied to various infrastructures and assets of ports, allowing for data collection, system modelling, data handling, intelligence, decision support capabilities, and carbon footprint reduction (GHG impact). More specifically, WP4 aims to (i) identify requirements and existing platforms, systems, and other sources of data; (ii) to define a modular architecture; (iii) to implement interoperable digital representations of the (non-)physical assets of ports; and implement the components that form the foundation for a Digital Twin (DT) for ports. These components will be reusable and shareable by participant ports, practitioners, and researchers. Interoperability will be achieved by leveraging semantic models and technologies (e.g., ontologies), which are, by nature, artifacts that can be adapted to meet the requirements of different practical contexts.

Digital tools using integrated real-time data from all partners along the transport chain would - by allowing a more efficient change of transport modes - strengthen intermodal transport. Considering the demand for efficient and reliable transport operation, real-time information, and the coverage of all modes, e.g., inland waterway, rail, road, are required.

By strengthening intermodal transport, digital tools can contribute to a modal shift from road to inland waterway and rail resulting in emission reduction. Digital tools may also facilitate the use of alternative fuels by better managing logistics and bunkering. A recent analysis by the International Transport Forum (ITF)[4] has found that the digitalization of the global supply chain supported by standardized freight data exchange – including wider adoption of open standards port community systems, can lead to a decrease in 22% in CO_2 emissions from freight transport by 2050[5]. This relative decrease in emissions would occur

[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[2] https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-transport
[3] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy_en
[4] https://www.itf-oecd.org/digitally-driven-operational-improvements-freight-emissions-reduction
[5] Relative to a reference scenario as defined in reference 4.

even within a global outlook of a 2.6-fold increase in freight transport activity and be accompanied by a 6% reduction in freight cost per kilometre.

Innovation and digital transition in logistics, transport and mobility

The digital transition in the Transport and Logistics sector is gaining momentum. This trend was noticeable until 2019, increasing in 2021. With the advent of the COVID-19 pandemic, significant adjustments have been made to global supply chains and logistics networks, which have intensified the need for digital transformation in this industry. The pandemic, and the war in Europe, have made several vulnerabilities in the sector very clear, including flexibility constraints and the difficulty of recovering rapidly from demand or supply shocks.

The transitional context created a need for digital operations with higher automation and less prone to interoperability issues regarding information exchange between stakeholders. Finally, this adverse context also designed the transition from traditional supply chains to omnichannel chains, which depend on real-time information exchange between actors, which could only be achieved by interoperable information systems and a data and systems architecture that is agreed-upon by all the actors involved in the supply chain.

The Transport and Logistics industry sector is struggling with significant inefficiencies. Manual shipping and low load consolidation practice result in a significant loss of efficiency and information. Insufficient digitization not only increases costs, but also makes it difficult to exploit the associated data. All these new challenges contribute to a substantial increase in the need for digital transition technologies in logistics and transport.

The urgency for smart green transition in the sector

Another major trend to consider is the pressure on the sector to become much more sustainable. The transport sector accounts for approximately a quarter of the EU greenhouse gas (GHG) emissions. According to recent projections by the ITF, global freight activity is expected to increase by 2.6-fold by 2050 relative to 2015 levels[6], which could lead to an increase in GHG emissions for the sector, as the increase in demand would outstrip the expected increases in energy efficiency.

In line with the climate strategy set out by the EGD[7], including the target of 90% GHG emissions reduction in the transport sector, specific policies for ports and supply chains are already planned for 2030 through the Fit For 55 legislative package[8]. These include the deployment of alternative fuels infrastructure (e.g., deployment of electricity and hydrogen charging and refuelling infrastructure) and the promotion of the use of alternative fuels in maritime transports, supported by FuelEU Maritime initiative[9]. The EC has accordingly defined goals for sea and inland ports for 2030 – e.g., that at least 90% of container ships and passenger ships have access to shore side electricity supply in sea ports and for inland ports at least one such installation is available.

Given that currently the transport sector is mainly dependent of fossil fuels to meet its demand (approximately 90% of total transport energy demand in EU-27[10]), operators in the

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[6] https://www.itf-oecd.org/sites/default/files/transport-outlook-executive-summary-2021-english.pdf
[7] https://www.consilium.europa.eu/en/policies/green-deal/
[8] https://www.consilium.europa.eu/en/press/press-releases/2022/06/02/fit-for-55-package-council-adopts-its-position-on-three-texts-relating-to-the-transport-sector/
[9] As adopted on the 19th of October 2022 by the European Parliament: https://www.europarl.europa.eu/doceo/document/TA-9-2022-10-19_EN.html
[10] https://www.eea.europa.eu/ims/use-of-renewable-energy-for

logistics and transport sector must take serious measures to meet the EU targets for 2030 and 2050, especially with the expected growth of demand in freight transport within this period. Meeting the EGD targets will thus require significant and consistent changes in the use of fuels in the sector, in the management and deployment of new port energy infrastructure, and in logistics operations in the next 5 to 10 years and beyond.

The Double Transition effect

The transport and logistics sector will struggle with a double transition in the coming years: Digital and Environmental. However, it should be considered that the digital transition – by itself – will be a very strong driver for the environmental transition by addressing relevant inefficiencies of the sector.

Sector-wide logistics assets (containers, rail cars, lorries, and trailers) are highly underutilized, and this has a significant impact in terms of GHG emissions: an estimated 1/3 of containers circulate empty, costing industry around €20 billion a year. In the road freight sector, it is estimated that more than 20% of lorries circulate empty, because of return journeys or inactive deliveries. On the other hand, those that are not empty circulate with an average occupancy rate of 52%. This situation is even more notorious in last-mile deliveries in cities, where the average vehicle occupancy rate is in most cases less than 40%. At EU level, this inefficiency is estimated to represent 124 million tonnes of CO_2 per year and approximately €160 billions of losses for the sector.

The new digital technologies applied to the sector thus necessarily have a dual mission: to resolve business inefficiencies, impacting costs, performance, and business growth, and, solving the inefficiency of the business, will have to deal with the improvement of the use of operational assets, which allows to generate substantially less GHG.

On the other hand, an increased digitisation of the transport sector could lead to increase in electricity demand e.g., to support the cloud-services and datacentres and associated electronic communications networks and services. At the EU level and considering the digitalisation of all sectors of the economy, this could represent upwards of 3% of total electricity consumption in EU-27 by 2025 according to a recent study[11]. In addition to characterizing the energy use from digitalisation of different sectors, the study also describes a set of technical and policy measures that the European Commission could put in place to ensure that the EU digital strategy is deployed in alignment with and to support the green transition as set out in the EGD. Some of these recommendations could be considered within the MAGPIE activities in WP4 in the design of the digital twin and tools to mitigate the impact of increased electricity demand to support digitalisation.

To conclude, there are substantial opportunities, innovation challenges and market growth related to digital and green transition solutions for the transport, logistics and ports sector. In many cases digital transition is per se an enabler of green transition, by promoting significant efficiency improvements in the utilization of transport and logistics assets

1.2 Work Package dependencies

This deliverable is mainly intended as a basis for further work in WP4 tasks, especially setting up the basis for the development of the digital twin and tools in further tasks. However, the

[11] https://digital-strategy.ec.europa.eu/en/library/energy-efficient-cloud-computing-technologies-and-policies-eco-friendly-cloud-market

activities carried out generally within WP4 interact with several activities and outputs in other MAGPIE work packages including:

- Demos and tool development in WP3, WP5 and WP6, where demo 2 (Smart Energy Systems), demo 3 (Shore Peak Power Shaving), demo 6 (Autonomous e-barge and transhipment), demo 7 (Green energy container), demo 9 (Green Connected Trucking) and demo 10 (Spreading road traffic) are expected to serve as the starting point for additional use cases of the implementation of the digital twin and tools to help define the overall DT architecture, the semantic model, and the functional requirements of the DT. On the other hand, the digital tools under development in WP4 are expected to: (i) provide support for data collection and processing, (ii) enable communication between different port actors and existing platforms, (iii) enable use of the digital tools for energy matching of supply and demand, GHG emissions reductions and logistics optimization in concrete demo cases, and (iv) provide access to a set of dashboards that would present information relevant to and that could aid in decision making.
- Market assessment in WP7, and evaluation of technological barriers towards the digitalisation of ports on aspects such as data governance and sovereignty, and ongoing projects within ports that address similar challenges to those within WP4.
- Support KPI monitoring in WP8, by collecting information and data from demos that can be eventually centralised and processed according to specific requirements to regularly produce indicators that can be used within WP8 and the demos (to monitor their progress towards meeting the KPIs).
- The contribution of the digitalization of ports to the green transition providing information to the Master Plan under development in WP9.
- Finally, relationship to WP10 in the exchange of practices and exploration of synergies with other sister projects (e.g., PIONEERS[12]) in terms of the contribution of digitalisation of ports to the decarbonizations of its operations.

1.3 Participating ports: an overview

The Port of Rotterdam (PoR) is the largest seaport in Europe and is frontrunner in the energy transition. PoR has the vision to become a zero-emission port by 2050. Together with the fellow ports HAROPA PORT, DeltaPort, and Sines, PoR supports the EGD sustainability goals. These ports want to use the demonstration results of the MAGPIE project to accelerate decarbonisation. The following subsections present a brief description of each port.

1.3.1 Port of Rotterdam

The Port of Rotterdam is the largest seaport in Europe, and the world's largest seaport outside of East Asia, located in and near the city of Rotterdam, in the province of South Holland in the Netherlands. From 1962 until 2004, it was the world's busiest port by annual cargo tonnage[13]. In 2020, PoR was the world's tenth-largest container port in terms of twenty-foot equivalent units (TEU) handled. In 2017, it was also the world's tenth-largest cargo port in terms of annual cargo tonnage[14].

[12] https://pioneers-ports.eu
[13] https://www.portofrotterdam.com/en
[14] https://www.ship-technology.com/analysis/feature-the-worlds-10-biggest-ports/

Covering 105 square kilometres (41 square miles), PoR now stretches over a distance of 40 kilometres (25 miles). It consists of the city centre's historic harbour area, including Delfshaven; the Maashaven/Rijnhaven/Feijenoord complex; the harbours around Nieuw-Mathenesse; Waalhaven; Vondelingenplaat; Eemhaven; Botlek; Europoort, situated along the Calandkanaal, Nieuwe Waterweg and Scheur; and the reclaimed Maasvlakte area, which projects into the North Sea. PoR is in the middle of the Rhine-Meuse-Scheldt delta. Rotterdam has five port concessions operated by separate companies under the overall authority of Rotterdam. The port is operated by the Port of Rotterdam Authority, originally a municipal body of the municipality of Rotterdam, but since January 2004, a government corporation jointly owned by the municipality of Rotterdam and the Dutch Ministry of Finance.

The aim of the PoR Authority is to strengthen the competitive position of the port as a logistics hub and a world-class industrial complex in terms of both size and quality. The ambition of the PoR Authority is to continuously improve the port in cooperation with various partners to be the most efficient, safe, and sustainable port in the world. To achieve this ambition, the Port Authority focuses on technological innovation, and sustainable development, management, and operations of the port.

1.3.2 HAROPA PORT

HAROPA PORT is the single port authority of the Seine Axis, it has been created by the merging of the ports of Le Havre, Rouen, and Paris. Since 1st of June 2021 these ports have been brought together in the same establishment[15]. HAROPA PORT is the 1st French port and is connected to all continents thanks to a leading international maritime offer (nearly 620 ports reached). It serves a vast hinterland whose heart is in the Seine valley and the Paris region, which form the largest French consumption basin. From Le Havre to Rouen, the port complex has 2.5 million m² of logistics warehouses in service. HAROPA PORT is now a transport and logistics system capable of offering a comprehensive end-to-end service offer. HAROPA Port generates annual maritime and river traffic of nearly 110 million tonnes, is the 4th northern European port in tonnage, and the 5th in TEUs.

1.3.3 DeltaPort

DeltaPort is an inland port, located in central Europe, near to the Rhine and Ruhr metropolitan regions and the ARA seaports[16] (Amsterdam, Rotterdam, and Antwerp). DeltaPort is the association of the Rhein-Lippe Port and the City Port, located within the municipal area of the City of Wesel, plus the Port of Emmelsum, located within the municipal area of the City of Voerde. By consolidating these three port areas in 2012 under one umbrella, a unique form of provision of space and services on the Lower Rhine for port-related commercial and industrial enterprises has emerged.

DeltaPort has the infrastructure links to numerous cargo handling options for loose bulk, break bulk, liquid, and heavy cargo, as well as containers. An additional plus is the great availability of very skilled and highly trained personnel in the fields of logistics, transport, business, and administration in the region.

[15] https://www.haropaport.com/en
[16] https://www.deltaport.de/en/deltaport/about-us/

1.3.4 Port of Sines

The Port of Sines[17] is located in the Southwest of Europe, 107 km south of Lisbon, on the intersection of the main international maritime routes, the East-West and North-South. The Port of Sines direct hinterland comprises all the south and midland part of Portugal. It is located at 150 km from Lisbon, 125 km from Évora, 100 km from Beja and 182 km from Faro.

The Port of Sines is the largest artificial port in Portugal, and a deep-water port, natural backgrounds to -28 m with specialized terminals that allow the movement of different types of goods. In addition to being the main port on the Atlantic seaboard of Portugal due to its geophysical characteristics, the port is the main gateway to the energy supply of Portugal, i.e., for container, natural gas, coal, oil, and its derivatives. Construction started in 1973 and the port came into operation in 1978. The Port of Sines Administration (APS) was created on the 14th of December of 1977. The port provides services such as: control of maritime traffic; pilotage, towage, and mooring; access control and surveillance; drinking water and bunkers; prevent accidents/pollution; repairs on board or ashore.

1.4 Outline

The remainder of this report is structured as follows:

Chapter 2 describes a sample of port decarbonization and digitalization projects implemented in MAGPIE ports, relevant to the scope of WP4, including testing and integration of new energy vectors, GHG tools and energy tools, green and smart logistics, and digitalization.

Chapter 3 describes and characterizes the existing and future digital platforms and services in ports. This chapter also identifies the main port services and assets, the actors responsible for providing such services and managing the assets of ports. An Enterprise Architecture approach was adopted to identify the existing digital platforms of ports, and how services and assets are mapped onto them. Finally, digitalization gaps related to supporting the decarbonization process are identified. These include, for instance, the inexistence or lack of integration of the digital platforms.

Chapter 4 describes the context and approach for developing the technological artifacts that form the DT for ports, particularly those related to data representation and exchange.

Chapter 5 describes the main Use Cases (UC) that are being developed as part of tasks T4.1, 4,2 and 4.3, to support the definition of the requirements and development of the digital twin and tools. Several use cases, at different levels of maturity, are described at the level of (i) the entire port ecosystem; (ii) digital tools under development; and (iii) demonstrators.

Chapter 6 provides the conclusions of this deliverable.

[17] https://www.apsinesalgarve.pt/en/

2 Overview of MAGPIE ports' digitalization and decarbonization projects

This section describes existing projects related with decarbonization and digitalization of ports, that could be potentially used as a basis for the tools that will be developed within WP4. The subject of the projects is related to MAGPIE objectives and encompasses the integration of new energy vectors, GHG and energy tools, green and smart logistics, and digitalization. The inventory and characterization of ongoing, or past, projects related to the MAGPIE topics, is meant to contribute to the identification of available data and tools that relevant to the development of the digital twin and tools.

2.1 Port of Rotterdam

The energy transition strategy of PoR is based on 4 pillars: (i) Efficiency and infrastructure; (ii) A new energy system; (iii) A new raw material and fuel system; and (iv) Sustainable transport. In 2021, the activities related with industrial production and electricity generation within the port of Rotterdam area accounted for 13,5% of CO_2 emissions in the Netherlands, making the region's contribution to the national climate objectives extremely important. In line with The Netherlands government strategy, PoR has set a goal of 55% of CO_2 emissions by 2030 and CO_2 neutrality by 2050. To achieve these results, PoR is implementing in different areas[18]. These projects – aimed at improving energy efficiency through improved logistics, provision of shore power, providing the infrastructure for clean fuels (e.g., Bio-LNG), renewable vectors (e.g., hydrogen), and supporting carbon capture and storage (CCS) – are projected to result in a reduction of 23 million tonnes in CO_2 emissions in 2030, which represents 35% of the total reduction goal at national level.

This section presents two examples of these flagship projects, which are more closely related with activities taking place in MAGPIE, namely supporting the development of the hydrogen supply chain and stations for exchangeable battery containers, which could significantly boost the decarbonisation and electrification of inland shipping.

Various H2 infrastructure projects

Almost three times the total energy consumption of the Netherlands is delivered to Rotterdam every year. That equates to 13 percent of the European Union's total energy needs. At present, this is mostly crude oil. Most of it is transported to Germany and the rest of Europe. The remainder is processed by industry in Rotterdam, mainly into feedstock for the chemical industry and fuels for the Dutch and international markets. This means that Rotterdam is Northwest Europe's energy port. This port function will continue in the future, but the energy flow will change. It will consist primarily of hydrogen. The role of hydrogen is growing. In addition to replacing natural gas to generate heat, hydrogen is developing into an important energy carrier. The advantages of establishing a hydrogen hub in Rotterdam are many. Large-scale use of hydrogen in industry can considerably reduce carbon emissions. A hydrogen network will also enable the port to continue to play a leading role internationally, as well as remain the motor of the national economy.

The Port Authority is working with various partners towards the introduction of a large-scale hydrogen network across the port complex, making Rotterdam an international hub for hydrogen production, import, application and transport to other countries in Northwest

[18] https://www.portofrotterdam.com/en

Europe[19]. The hub will also enable Rotterdam to maintain its position as important energy port for Northwest Europe in the future. PoR will have a hydrogen system that combines production and use, particularly in industry, but also imports and transit flows of hydrogen to other parts of the Netherlands and Northwest Europe. The Port Authority and Gasunie are working on an initiative to have a backbone for hydrogen running through the port as early as 2023. This main transport pipeline will supply companies with hydrogen produced at conversion parks in the port. The backbone will be connected to Gasunie's national infrastructure throughout the Netherlands and to corridors leading to industrial areas in Chemelot in Limburg, and North Rhine-Westphalia. In time, there are also plans for a terminal to facilitate imports of hydrogen. This will give Rotterdam a leading infrastructure in the field of hydrogen that will stimulate market development. In addition to making an important contribution to the national climate targets, a hydrogen system of this kind will also boost the earning power of the port complex.

Not only transport of hydrogen, but also transport with hydrogen as transport fuel needs to be developed. PoR and port companies, together with other stakeholders, support development of many projects, such as, bunker stations for inland shipping (RH2INE project[20]), tank stations for trucks (Hytruck project[21]) and hydrogen-based fuels for aviation (The Hague Airport pilot project[22]). For industry, it is expected that hydrogen will grow rapidly as feedstock for refining and chemicals, replacing crude oil more and more.

ZES (Zero Emission Services for barges)

Zero Emission Services (ZES[23]) offers a new energy system to make inland shipping more sustainable. The system provided by ZES will also be tested in demo 6 and demo 7 of MAGPIE, and within PIONEERS. The system consists of a complete product and services package for emission-free sailing based on exchangeable battery containers with green electricity, charging stations, technical support, and an innovative payment concept for barge owners. The service offers users a future-proof solution that provides exchangeable energy containers charged with green electricity. Once depleted, the skippers can quickly exchange the containers for a fully charged one at one of the exchange and charging stations. These stations form part of an open access network.

ZES makes more sustainable inland shipping possible with a new, clean, ready to face the competition with fossil fuels, and affordable transport system. The shares of ZES are held by four companies: supplier of emission-free transportation ecosystems Ebusco, ING, maritime technology company Wärtsilä and the Port of Rotterdam Authority. The Ministry of Infrastructure & Water Management is supporting this initiative together with the Province of South Holland.

2.2 HAROPA PORT

The sustainability strategy of HAROPA PORT is based on three priority areas: promoting smart logistics solutions, promoting a modal shift to limit the emission of greenhouse gases,

[19] https://www.portofrotterdam.com/en/port-future/energy-transition/ongoing-projects/hydrogen-rotterdam
[20] https://www.rh2ine.eu/
[21] http://www.hytruck.nl/en/over-hytruck/
[22] https://www.stichtingrhia.nl/en/about-rhia/
[23] https://www.portofrotterdam.com/en/news-and-press-releases/first-emission-free-inland-shipping-vessel-on-energy-containers-in-service

and reducing the impact of port activities integrating the ports into their natural and urban environment. HAROPA PORT is also supporting green initiatives such as: the development of new fuels and electrification of the fleet. The port is developing several tools and projects to improve its operations as well as promoting decarbonization that are closely related to the topics explored in MAGPIE:

Borne & Eau

The Borne & Eau[39] project focuses on providing solutions for the electrical power supply for river freight and passenger vessels. The objective is to set up a system of OPS terminals for inland waterway vessels carrying goods in port or on standby, replacing the generators currently used on board and necessary for the operation of domestic and safety equipment. It consists in the deployment of 78 water/electricity terminals for quayside supply of freight and river cruise ships across the Sein axis. Harmonised tariffs and different types of sockets, 16A, 32A et 63A, for full interoperability. This project is supported by the European Commission through the Connecting Europe Facility.

OPS-SEE

The project aims at electrification of the cruise terminal in Le Havre port, due in 2024-2025 and electrification (OPS-SEE) of the quays of PORT 2000 container terminal in Le Havre port, due in 2028. The OPS of maritime vessels, a strategy has been initiated since 2018 at port of Le Havre by prioritizing initially the cruise. Also, container traffic should follow with a test on an autonomous power generation unit powered for instance by LNG. Le Havre is also studying solutions for the implementation of mobile connections on the existing container quays where the space is too small for the installation of conventional OPS equipment. OPS for container vessels is in the process of organizing a test with a shipping company to supply a container ship from an autonomous production unit running on LNG. The unit will produce up to a power of 3 MW at a frequency of 60 Hz. In addition, the port is working on the development of a prototype that will allow the OPS to be implemented on the quays of the Port 2000 terminal (large container terminal in Le Havre) where the space between the front rail crane and the quay edge is too narrow to integrate a classic Cable Management System (CMS).

In line with the goals of OPS-SEE, HAROPA PORT and PoR have signed a MoU under the umbrela of the World Port Climate Action Programme (WPCAP) with port of Antwerp-Zeebrugge, Bremenports and Hamburg to implement OPS before 2028 for Ultra Large Container Vessels (ULCV).

H2SHIPS

The H2SHIPS[41] project aims to demonstrate the technical and economic feasibility of hydrogen bunkering and propulsion for shipping and will identify the conditions for successful market entry for the technology. Two pilot projects will be implemented: a new hydrogen powered port vessel will be built in Amsterdam, and in Belgium a H2 refuelling system suitable for open sea operation will be developed and tested. A further major output will be an action plan for the implementation on the river Seine in Paris in 2022. H2SHIPS will demonstrate the added value of hydrogen for water transport and develop a blueprint for its adoption across North-West of Europe. The project received funding from Interreg North-West Europe between 2019 and 2022, has 13 partners from 5 countries and is coordinated by Europäisches Institut für Energieforschung (EIFER). This project is support by INTERREG V B NEW programme.

LH2

The LH2[42] project in Le Havre, carried out by the Compagnie Industrielle Maritime and Hynamics on hydrogen for mobility, involves the conversion of a storage area into an electrolyser with a power of 2 MW in 2024. A partnership has been launched with Le Havre Metropolitan Authority, Transdev, LHSD and Synerzip. The acquisition of 18 hydrogen buses completes this project.

Normand'Hy

The Normand'Hy project aims to contribute to creating a French and European low-carbon hydrogen sector and to the decarbonisation of the Normandy industrial basin. It will also contribute to heavy-duty hydrogen mobility in this important industrial area. The electrolysers will have a capacity of 200 MW in the first phase and will be located in Port-Jérôme, Normandy. It will be one of the first electrolysers of this size in operation in the world and is planned to be commissioned in 2025. The renewable hydrogen production can reach 3 GW electrolysis capacity by 2030.

CCUS prefeasibility

The consortium formed by Total Energies, Yara, Exxon, Borealis and Air Liquide launched a CO_2 capture, utilisation and storage (CCUS) prefeasibility study along the Seine waterway in 2020. The aims of the study were (i) create a realistic deployment plan of CCUS along the Seine waterway, (ii) estimate its cost based on a preliminary design, and (iii) anchor this project in the European CCUS projects' network. Main conclusions from the study were (i) carbon capture and storage CCS is essential to reach the French decarbonization targets in the region, (ii) implementing CCUS on the industrial sites along the Seine waterway would maintain jobs and create new ones to ensure sustainable industries in a decarbonized future, and (iii) the technology is costly but beneficial for the society. It is amongst the measures that would help reach carbon neutrality at a low cost for the society.

2.3 DeltaPort

DeltaPort has multimodal connections to all transport systems and cross-border pipeline networks. The port is developing several tools and projects to improve its operations as well as promoting decarbonization which are reviewed in the following paragraphs.

EDPS (Event Driven Process Stimulator)

Event Driven Process Stimulator (EDPS), an ongoing project, is a coupling between port side services such as AIS and operator platforms (TMS) in order to be able to "trigger" follow-up processes automatically when defined milestones are reached. For example, when a barge is expected from Port of Rotterdam, it drives through a geofencing grid, each radius limit is triggering predefined processes.

i. When the barge crosses the outermost grid limit, the terminal target area for the containers arriving by the barge and to be unloaded has to be cleared in order to provide sufficient storage capacity in the crane runway.
ii. When the next defined grid limit is reached, the pre-storage for the containers to be loaded, which are already at the terminal, could be started. This pre-stowage in the terminal should be coupled and synchronized with the barge's stowage plan in order to optimize the loading sequence of the containers to be handled before the loading phase begins.

These simple steps improve the operational performance of the terminal task which in turn decrease the energy consumption at the operations level. For example, the optimized loading sequence can already be carried out physically by means of stowage processes within the stacking columns of the crane runway that are decoupled in time from the loading process and therefore precede them in time. If the unloading process is prepared in unison, in so-called double cycles of the container cranes used, a loading and unloading process can be combined with each trolley run without stowing. Thus, the "Event Driven Process Stimulator" could be used to achieve a significant increase in productivity in the waterside cargo handling process by triggering process impulses in time. Previous example can of course be applied to the handling of all modes of transport to be planned in the terminal and only needed to be adapted in the syntax.

The defined milestones for an incoming barge can be seen in Figure 1.

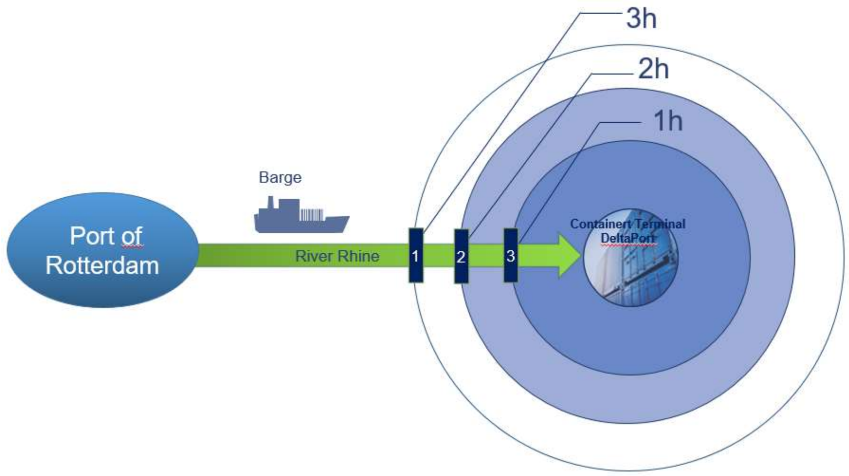

Figure 1 – Visualization process chain import (EDPS)

EcoPort813 – H2UB DeltaPort

DeltaPort has recognized the potential of hydrogen as a future technology for the Lower Rhine region and wants to achieve CO_2 neutrality for its inland ports. Europe is moving away from fossil fuels like coal, mineral oils or gas as energy sources. In Germany the coal phase-out is planned for 2038, maybe earlier. This means that 42 percent of the volume of cargo on waterways will be eliminated. This leads to essential business implications for the future of ports. It's important to create new cargo alternatives. H2 as an ecological approach for transformation and as an economic necessity could be such an alternative for inland shipping.

EcoPort813 – H2UB DeltaPort aims to transfer and store green Hydrogen-based fuels which is mainly used for inland navigation, rail traffic, trucks, filling station network, and public transport. It can be produced from electrolysers on the North Sea using offshore wind energy or be purchased from sunny countries, e.g., Maghreb which use solar power for H2 production. H2 could be transported via the import hub Rotterdam in different variants and with different modes of transport, e.g., tankers for liquefied H2 gas (Liquid Organic Hydrogen Carrier- LOHC), pipelines, and/ or a technically adapted inland tanker fleet. Also, technical redesign of existing tank farms for storage of H2 is necessary in the hinterland. A conceptual design for the supply network of H2 can be seen in Figure 2.

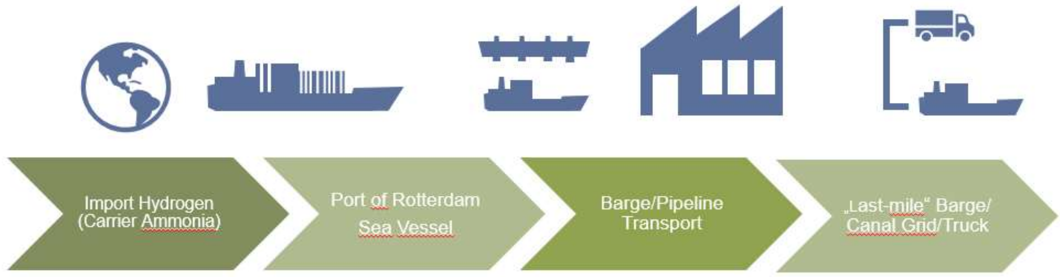

Figure 2 – Import Supply Chain Hydrogen (Carrier Ammonia)

Log4NRW

The Log4NRW project addresses logistical problems resulting from road congestion in North Rhine Westphalia (NRW; federal state of western Germany). Major highway routes and urban road networks suffer from congestion resulting from heavy traffic volumes. Moreover, maintenance condition of the infrastructure is poor, causing restrictions for truck operation. Various (highway) bridges are closed for heavy trucks.

The project proposes a modal shift from road to inland waterway and rail. This would reduce truck traffic which in addition to a considerable reduction in road congestion in the Ruhr area, particularly, reduces CO2 emissions since the carbon footprint per ton-km is considerably lower for barges than that for trucks. A side impact could be reducing the need for long haul trips by the truck and increasing efficiency of truck operation in local last-mile operation.

The Log4NRW project will create a network of inland waterways and railways between the key terminals of Wesel, Cologne, Dortmund, and Siegen (See Figure 3). These terminals are outside of the congestion cluster of NRW and would span a "logistic square" around the core area of NRW. Combined transport (CT) locations should be networked in such a way that flows of goods are bundled outside of the congestion regions and can flow faster and thus more safely thanks to the possibility of specifically bypassing traffic bottlenecks. The source of traffic originating from this area, or the destination of traffic intended for this square, can switch from the truck to the alternative modes of transport like inland waterway and/or rail at the corner points of Wesel, Cologne, Siegen and Dortmund. Between Wesel and Cologne, as well as between Wesel and Dortmund, the inland waterway vessel should primarily contribute to the relocation, between Cologne and Siegen, as well as Siegen and Dortmund, the rail transport carrier should be used. In particular, the connection between the Wesel, Cologne and Dortmund locations can be operated synchro-modally, as there are waterway and rail connections. These flows of goods would involve in particular export and import flows from the northern ports (Hamburg, Bremerhaven and Wilhelmshaven) and from the western ports (Amsterdam, Rotterdam and Antwerp).

Along this square it is planned to implement a conveyor belt system with barge and rail. Using this system, cargo for central NRW would be routed via the key terminals. As a result, the inland waterway and barge operation would be extended to the hinterland and distances of last mile truck operation could be reduced. Moreover, in these inland ports installed as macro-distribution centres, containerized consumer goods coming from the western or northern ports, mainly from the Asian economic area, could be received, unloaded, and sorted as well as commissioned according to postal codes for urban core areas. The container would be suitable as an ideal transport container and could also be converted into a micro-depot at the destination transhipment points. In particular, the topic of the last mile and the last mile distribution of the flow of goods could be optimized by reactivating closed coal mine ports in the Western German canal network, including the alternative mode of transport inland waterway. Due to the constant water level in the canal system, containerized goods could be loaded and unloaded from the barge using simple vertical handling technology. A mobile reach stacker would be sufficient for container handling. The establishment of micro-distribution centres for handling small-scale general cargo traffic would be conceivable. Within the framework of urban logistics, the fine distribution of these micro-depots could be realized with alternative transport options, such as cargo bikes.

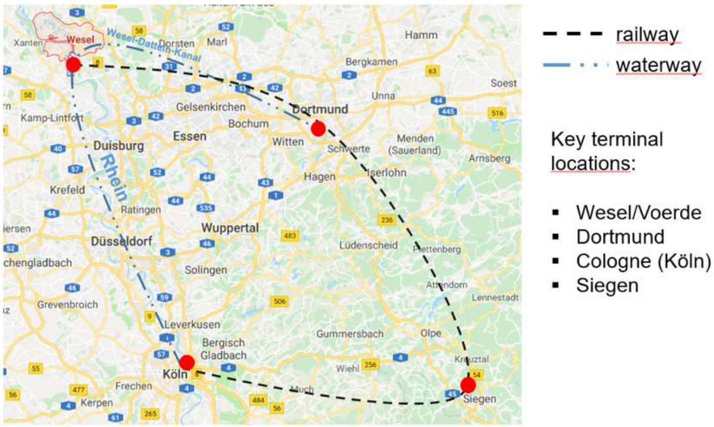

Figure 3 – Map of the logistic square "log4NRW"

2.4 Port of Sines

APS has defined a series of projects to apply a new strategic line to be the traffic promoter, changing the role from infrastructure manager to network manager, building from their comprehensive knowledge of all the business processes and participation in the digital business processes specification and development, which allows APS to play a key role in promotion of decarbonization and energy transition.

Nexus Agenda

The Nexus project aims to achieve a greener port through innovation and digitalization. The implementation phase of the project is about to start and will last until the end of 2025. The project involves about 35 entities, including companies, start-ups, tech providers, and research and academic institutions, representing the entire innovation supply chain.

The nexus agenda will be applied in three layers. The first layer will promote the emergence of new start-ups, making port data available so that they can apply it to new products and services, the second layer intents to develop products and services that will contribute to the green and digital transition, and the third layer involves several projects for the decarbonization of the port activities, e.g., a new tugboat and retrofitted speedboats and energy production based on renewables (e.g., solar, wind and waves), all represented on a digital twin.

In the first layer, the Nexus open data collaboration platform will curate, consolidate, normalise, and process a massive amount of high-quality multimodal network data, making it available via an open data collaboration marketplace. By creating a fully-fledged data-sharing and collaboration context it will stimulate innovation and the utilization of artificial intelligence. The platform will host applications and APIs for digital and green transition, that will be fully open for all companies, including SMEs, thus creating a strong incentive for digital innovation in a competitive context. It will also offer an open data marketplace and a location services marketplace, that will monetise on logistics events, that can be consumed by external systems via the APIs offered.

A substantial part of the work in the platform will be related to gathering increasingly more data. It will tap on to the data pool of core sector-wide platforms, such as the Logistics Single Window (JUL) platform and all the authorities' systems. It will also negotiate data-sharing worldwide with other platforms, such as Port Community Systems, Logistics and Transport Marketplaces and Visibility platforms. Finally, all the NEXUS federated apps and the hardware assets (via their digital twins) will also be key data providers. A schematic view of the data collaboration platform can be seen in Figure 4.

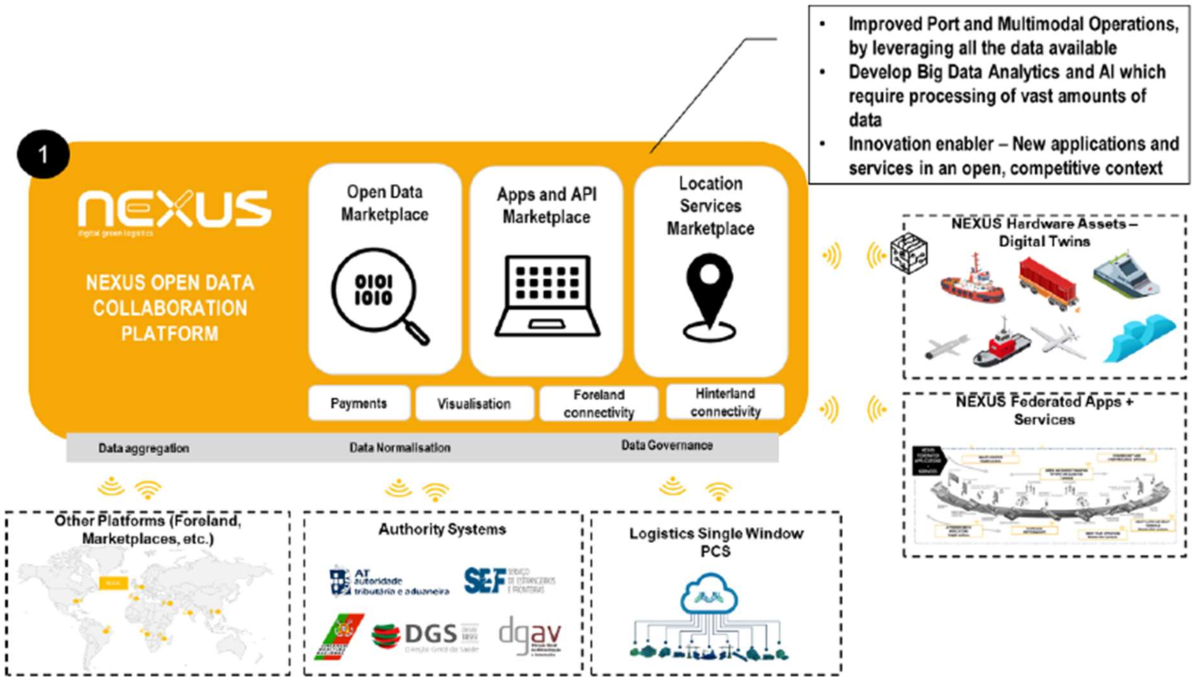

Figure 4 - NEXUS Open Data Collaboration Platform

In the second layer, nexus federated applications and services will produce 25 applications and services that will be included in the Apps and API portfolio of the Open Data Collaboration Platform and cover areas as different as smart logistics, green and energy transition, cybersecurity, artificial intelligence, 5G connection, and smart trains, gates or terminals. These apps and services will greatly benefit from all the high-quality logistics data available and from the synergies with other products in the ecosystem. The digital products and services will have their own unique selling proposition and will be prepared to be commercialized both via NEXUS but also as stand-alone solutions. Figure 5 illustrates the federated applications and services and their collaborative approach.

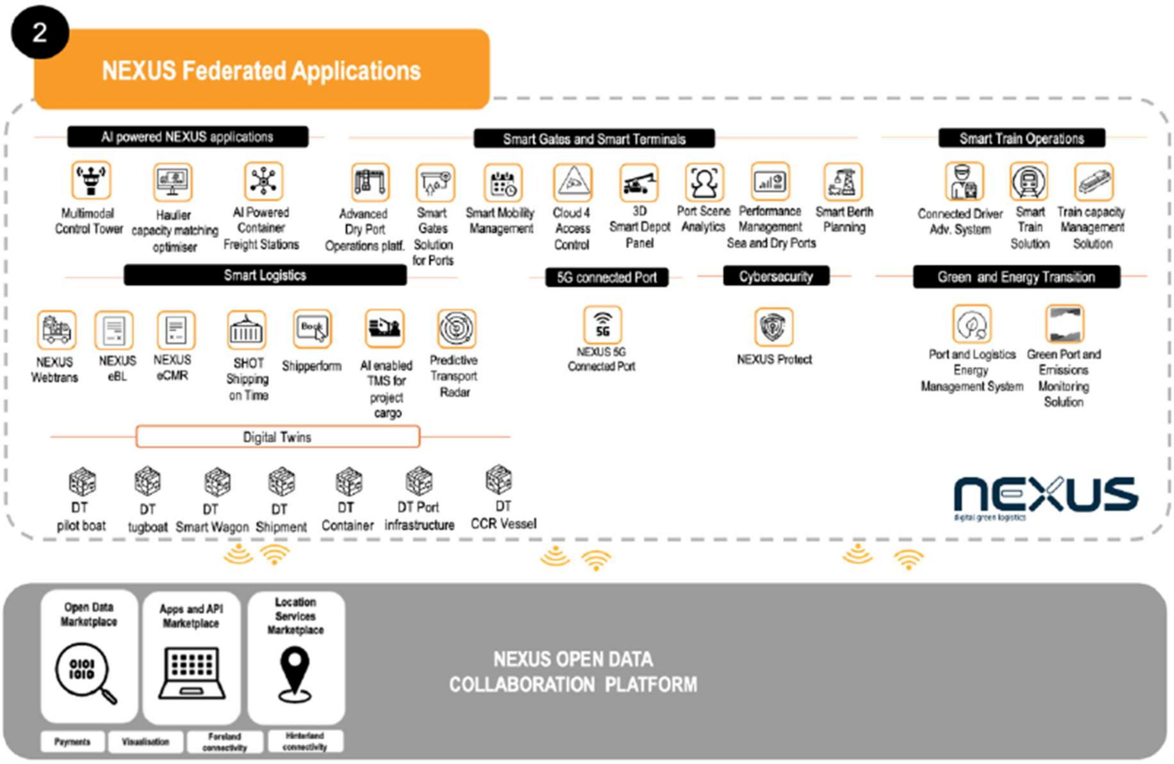

Figure 5 – NEXUS Federated Applications

The third layer, NEXUS hardware assets consist of innovative hardware-based products, providing considerable synergies with the Open Data Collaboration Platform and all the Applications and Services. Each of these will have its own Digital Twin representation that will be connected to the Platform, to share and receive data considered useful for improved performance of the operations. The hardware-based products include:

- 3 zero emission smart boats: Pilot boat, Tugboat and Smart Command and Control Rescue Vessel - with full electric propulsion and embedded digital twin for operations and energy consumption data interoperability.
- An emission monitoring and surveillance aerial UAV, a water quality monitoring and surveillance underwater UAV and an aerial UAV for inspections of wind-turbine blades and photovoltaic panels.
- A clean anergy production system based on wave energy (REEFs).

The hardware-based products can be seen in Figure 6.

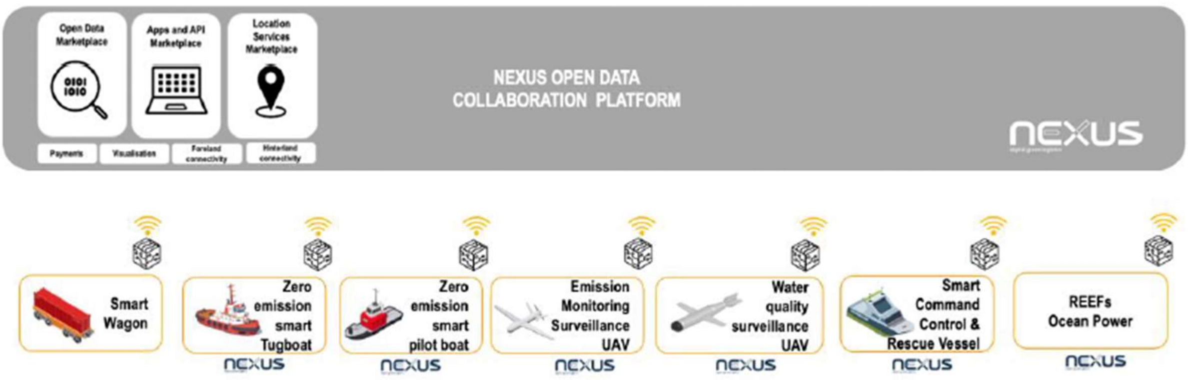

Figure 6 – NEXUS hardware-based products

Smart Wagon

The Smart Wagon Innovation Agenda will design and develop an innovative wagon concept for the transport of goods incorporating sensors. There are significant synergies between this product and the NEXUS ecosystem. Therefore, the Smart Wagon will be included as one of the Hardware Assets of NEXUS, which will develop a Digital Twin of the Smart Wagon that will share and receive data with the ecosystem. Also, there will be a digital application in NEXUS – The Smart Train App - that will explore the sensors capabilities of the Smart Wagon.

H2Sines.RDAM

In September 2020, the Port of Rotterdam invited the Port of Sines to integrate the H2Sines.RDAM project, which, in general terms, intends to develop an H2 corridor aiming at developing the production of Green Hydrogen in Sines, convert it into Liquid H2 through a liquefaction process, and export it via the Port of Sines to the Port of Rotterdam.

The main objectives of this project, in line with the fulfilment of the European Green Deal, are the following:

- Production and export of 100 tonnes/day of Liquid Hydrogen (LH2), in accordance with the RED II – Renewable Energy Directive of the European Union, in an initial phase, while, on a second phase, this production capacity will reach 300 tons/day;
- Demonstrate the technical feasibility of producing and transporting LH2 by sea;
- Promote the decarbonisation of critical infrastructure, within the scope of the RTE – Trans-European Transport Network, through the import of renewable molecules by the Port of Rotterdam;
- To directly and efficiently contribute to the goal of reducing GHG emissions by 55% by 2030;
- Reduce the dependence on Russia, in line with REPowerEU, by connecting the Sines region, which offers a large capacity for renewable energy production, with the Rotterdam region.
- Creation of more than 3,000 jobs during the construction phase of the project, and more than 360 effective jobs at the start of the project.

On the Sines side, the project will consist of the installation of a production unit for green H2, which includes an electrolyser, a liquefaction unit and a tank area for the storage of LH2, as well as a berth for exporting LH2 by ship to the Port of Rotterdam, in methane tankers with a capacity of around 13,000 m3; the first vessel is expected to be operated in 2027.

MadoquaPower2X

MadoquaPower2X is developing a world-leading green hydrogen and renewable ammonia project located in the Sines ZILS - Industrial and Logistic Zone. MadoquaPower2X is a consortium comprised of Madoqua Renewables, Power2X and Copenhagen Infrastructure Partners (CIP).

The project involves the production of green hydrogen using established alkaline-water electrolyser technology and the production of green ammonia through the Haber-Bosch process. Hydrogen will be transported through the local hydrogen grid and can be used by other local players, as well as blended into the natural gas grid. The green ammonia will be transported by pipeline to the Port of Sines and loaded for export and/or used as maritime fuel and is an attractive option for European green fertilizer manufacturing.

The project will use renewable energy to produce the green hydrogen and green ammonia. The electricity will primarily be provided through a renewable energy community with access to dedicated solar and wind assets in Portugal which are being developed in parallel. This approach allows for a secure and dedicated renewable power supply for the full lifetime of the project.

3 Characterization of ports, current and future digital platforms and services

In this section, an Enterprise Architecture approach was carried out to characterise ports on regards to their organisation (Section 3.1) as well as the typology proposed in the deliverable of Task 9.1 within WP9; actors and main roles within the port ecosystems (Section 3.2). The main goal consisted of understanding how current and future digital platforms (Section 3.3) are expected to support the technology-enabled services provided by the ports (Section 3.4), in the domain of port logistics and decarbonization. Section 3.5 describes the existing gaps related to the scarcity or limitations of current digital platforms and services towards promoting the efficiency of port operations and reducing emissions levels and energy consumption.

3.1 Port services and assets

3.1.1 Port of Rotterdam

The Port of Rotterdam spans through 12,600 hectares of land. In 2021, 468.7 million tonnes of cargo and 15.3 million TEU containers were handled. The port is an intermodal hub with connections to road, rail, and waterways (e.g., barges) networks. The port authority is committed to strengthening the Trans-European Networks – Transport (TEN-T). Port Authority assets involved are the waterways, water bottom, quay walls, bollards, fenders, roads, pipe strips, masts, etc. Third party (private) assets involved are terminal and industrial equipment, energy network, pipelines, and moving modalities. Following the typology proposed within WP9, the Port of Rotterdam is a major hub regarding hinterland transport due to the variety of modal shift (h4). Energy-related activities are oriented towards petrochemical and power generation (e4), and the port is self-sufficient in energy generation, with a balanced business-oriented profile (f3). The projects described in Chapter 2 assert a long-term strategy towards energy transition involving external (g2) and internal (g3) stakeholders as well.

3.1.2 HAROPA PORT

HAROPA PORT is the river-sea port of the Seine axis in France, one single authority encompassing three ports/area management:

1. Le Havre (maritime port): A gateway seaport and port of call for the world's biggest container ships.
2. Rouen (maritime port): The leading West European port for grain and a specialist breakbulk port.
3. Paris (inland port): A network of 70 urban ports and the springboard for last-mile logistics.

HAROPA PORT stretches across 16,000 hectares, of which 5,000 (about 30%) consist of protected areas dedicated to natural habitats. The entire axis accounts for more than 500 km of navigable waterways. The particularity of HAROPA PORT's market offering is that it proposes an integrated logistics and multimodal solutions from the French coast at Le Havre and Rouen into the centre of Paris and along the upstream portion of the Seine. From the geographical point of view, it is the first major port of call in Northern Europe for imports and the last for exports.

The commercial offer is represented by nearly 650 ports of call worldwide, almost 3,800 commercial propositions and 157 direct connections. In 2021, HAROPA PORT reported 83.6

million tonnes of maritime traffic, 22.5 million tonnes of river traffic and 3.1 million TEUs of maritime container traffic.

The port authority's area includes a wide variety of sites from 5,000 to 175,000 sq. m. – from vacant lots for construction to turnkey warehouses and office buildings. In 2019 1,545,000 sq. m. of logistics warehousing were offered on port land, the plan is to increase this figure up to 21% by 2025.

HAROPA PORT is a port fully focused on intermodality and massification of freight flows. Connections to road, rail and inland waterways are provided all along the axis. Four multimodal terminals are currently present: Le Havre, Rouen, Gennevilliers (Paris), Bonneuil-sur-Marne (Paris). One additional fully multimodal platform is planned within the framework of the project PSMO-Paris Seine Metropole Ouest. There are around fifty weekly river services and more than 60 rail roundtrips a week to 16 destinations including Novara, in Italy, and Chavornay, in Switzerland.

There are 57 maritime terminals located across axis, 25 of which provide infrastructure adapted to a specific type of traffic:

- 10 maritime container terminals
- 5 inland container terminals
- 7 conventional terminals specially equipped for exceptional loads
- 2 ro-ro terminals capable of loading and unloading more than 1,000 vehicles/day
- 1 cross-channel terminal

The decarbonisation of the Seine axis, in partnership with port and territorial actors, also involves the electrification of the quays, the development of the alternative fuels' infrastructure and the capture of CO_2. Several projects on hydrogen and ammoniac are being prepared within the Seine's region. Regarding electrification, 89 electrical charging stations along the Seine axis. will be added to the 13 already installed for the electrification of maritime and river quays for both cruise ships and freight. HAROPA PORT is also a major hub regarding hinterland transport due to the variety of modal shift (h4). Energy-related activities are petrochemical dominated (e2), and the port is import-reliant on energy generation as described in 3.2.2 (f1). The projects described in Chapter 2 seeks a long term strategy towards energy transition involving external (g2) and internal (g3) stakeholders.

3.1.3 DeltaPort

DeltaPort spans through 130 hectares of land at the Lower Rhine and encompasses three port areas: (i) City Port of Wesel; (ii) Port of Voerde-Emmelsum; (iii) Rhine-Lippe Port Wesel. As an intermodal hub, cargo is handled and transhipped at DeltaPort. In 2021, 4,0 million tonnes of cargo and 111,000 TEU containers have been handled. The hub is connected to road, inland waterway, rail, and pipeline networks. Various terminals and logistic sites for a wide range of commodities are located in the port areas. Logistic sites in the port are related to cargo handling. For instance, warehouses exist for container cargo, tank storage for petrochemical products, silos for agricultural goods and open storage areas for building material. Moreover, industrial sites are located in the port. They have a link to the port and the transport/logistic services.

Transport and logistic services include transhipment, handling (e.g. deconsolidation, warehousing etc.) and hinterland transport to serve the catchment area. DeltaPort is not directly involved in the energy supply for port sites and transport vehicles. Considering the need to reduce the use of fossil fuels, the port is working on the development to use alternative fuels such as hydrogen. Infrastructure and tank storage facilities are available to become a hub for hydrogen imports. DeltaPort is also a major hub regarding hinterland transport due to the variety of modal shift (h4). Energy-related activities are petrochemical dominated by fossil fuels (e2), and the port is import-reliant on energy generation as described in 3.2.3 (f1), although efforts towards green energy transition involving external (g2) and internal (g3) stakeholders are being carried out.

3.1.4 Port of Sines

The Port of Sines Authority (APS) was created on December 14, 1977, and spans through 2,000 hectares of land, including the Industrial and Logistics Zone (ZIL). The company was endowed the management and exploitation of the Port of Sines, whose construction had begun in 1973. APS was settled as a public institute with legal personality, being financially and administratively independent. By that time, the company was responsible for the management and exploitation of the single terminal in operation – the Oil Terminal (nowadays Liquid Bulk Terminal).

The Port of Sines provides the following services to vessels and cargo:

- Maritime Traffic Control
- Pilotage
- Tug services.
- Mooring services.
- Handling of cargoes with or without stevedores' services.
- Handling and storage of cargo. There are also tanks for the storage of liquid bulk inside the TGLS – Liquid Bulk Terminal area.
- Wastes reception services.
- Bunkers supply.
- Utilities supplying service, e.g., fresh water, steam, compressed air within the TGLS area, and power supply.
- Maritime transport services.
- Services for onboard supplying of food, spare parts, and other consumables, under a free competition basis.
- Safety services, including firefighting and accidents intervention, explosions, and pollution issues.

The strategic options for the Port of Sines 2020-2030 are based on three Strategic Axes, whose main objective is to strengthen centrality and connectivity based on a network management or system coordination model, and a commitment to sustainability environmental and social, this strategic plan aims to make Sines a Port to the World, bringing the World to the port, while preparing it for an increasingly modern, innovative, digital and efficient future.

Having as strategic goals the capture of Iberian cargo to reach a share of 8% in the total associated with foreign trade, expand the activity of ZILs and Logistics Activities Zone (ZAL) and ensure that the new economic activities contribute towards more than 40% to the movements of the port, as well as how to achieve leadership in stakeholder satisfaction with regard to the attributes of "internal connectivity", "cost / price" and "hinterland", the Port of Sines sets the bar on excellence, based on a value proposition with a vision for the future.

The Port of Sines is also a minor hub regarding hinterland transport: modal shift consists of road and rail transport (h2). Energy-related activities are petrochemical dominated by fossil fuels (e2), and the port is import-reliant on energy generation as described in 3.2.4 (f1), although efforts towards green energy transition involving external (g2) and internal (g3) stakeholders are being carried out.

3.2 Actors and responsibilities

3.2.1 Port of Rotterdam

The Port of Rotterdam is a landlord port. The Port Authority is responsible for infrastructure investments in public areas, e.g., roads, waterways, VTS, and traffic planning. Stakeholders include customers, port visitors, maritime services, municipality, government, safety & security services, (sub)contractors. The port neither owns nor manages the electrical network within the port ecosystem.

The port authority does not own nor manage the electricity network within the port area. The network is owned and managed by Tennet (national network operator) and Stedin (local network operator). Eneco is responsible for the energy supply.

The established companies (e.g., terminals) are responsible for the development of the superstructures at the port. This includes handling equipment such as gantry cranes and reach stackers. The Port authority is responsible for infrastructure investments in the public area, e.g., roads, waterways.

3.2.2 HAROPA PORT

HAROPA PORT is (also) a landlord port. The port authority owns the land and is responsible for the infrastructure and site development across the 16,000 hectares. Transport and logistic operation are under responsibility of transport operators and logistic service providers.

Regarding data on operations related to transportation and logistics, these are collected by terminal operators and transport companies. There is no institutionalized system in place for the exchange or sharing of data between terminal/transport operators and the port authority.

HAROPA PORT is not an electricity network operator within the meaning of the regulations and is therefore not authorized to distribute and resell electrical energy. The port authority does not own nor manage the electrical network within the port area. It is own and managed by RTE and ENEDIS. RTE takes charge of the electricity from the producer to the distributor. ENEDIS distributes the same electricity to different customers under contract with an electricity supplier. HAROPA PORT supplies its own facilities (mobile structures, buildings, public lighting, median lighting, intersections with traffic lights, etc.) as well as certain buildings occupied by customers. Private ownerships are supplied directly on the French public 20kV distribution network (ENEDIS) or by the electricity transmission network (RTE) for 90/225 or 400 kV (TOTAL, etc.). Working groups are regularly organised between HAROPA PORT, RTE and ENEDIS on the monitoring of electricity consumption of clients. The granularity is not to be easily defined since there is no fixed frequency for such meetings. The closest estimation would be monthly.

Monitoring and collection of GHG emissions is done at "etablissement"-level every year. The port authority does not monitor overall energy consumption and emissions of the stakeholders located and operating within the port area.

HAROPA PORT is a port particularly active regarding projects focused on energy transition, both through planning and federating actions. On the one hand, by directing the establishment of alternative fuel production sites on the land, and when this is not possible, by allocating the right land while directing the use of alternative fuels towards the port ecosystem; on the other hand, through connecting stakeholders, by financially encouraging common initiatives, by communicating on best practices to generate new requests.

3.2.3 DeltaPort

The port is organised as a landlord port. The port authority is responsible for the infrastructure and site development in the ports. Transport and logistic operation are under responsibility of transport operators and logistic service providers.

Data on transhipment and transport operation at DeltaPort is managed by terminal and transport operators. Data exchange might be implemented between partners/modes in some segments, e.g., container operation. However, transport data is only shared with the port authority for the collection of port fees.

The established companies are responsible to develop the superstructure on the port sites. This includes handling equipment such as gantry cranes and reach stackers. Moreover, all buildings on the sites, such as logistic warehouses or industrial production facilities, are established by the resident company.

Energy supply for port sites is under the responsibility of local energy suppliers. The port authority does neither manage nor monitor energy consumption and emissions of port sites. The port authority does not have any information about the actual application of the port companies' energy and emission management or monitoring.

The development of transport and logistic services utilising inland waterway and rail modes via the hub DeltaPort aims for a reduction of energy consumption and emissions. The hub with its strong multimodal links provides the fundament for modal shift from road to inland waterway and rail. Furthermore, developing port infrastructure and services should contribute to additional modal shift. The port authority does not monitor overall energy consumption and emission. Transport operators may provide tools for clients to calculate emission of transport services. For instance, the Intermodal Tariff Information System by the container terminal and transport operator Contargo provides, beside tariff information, emission figures for alternative transport options.

The energy supply for vehicles such as bunkering of barges is under the responsibility of operators. However, DeltaPort aims on the strengthening of alternative fuels such as in particular hydrogen. They work together with partners on the development of DeltaPort into a hydrogen hub and the strengthening of the use of hydrogen as alternative fuel for transport operation. Interested partners cooperate in a registered association. Investment responsibilities are determined by the landlord model. The port authority would be responsible to prepare a suitable site and infrastructure for a hydrogen hub and respectively bunkering station. The settled company would be responsible to establish the superstructure, e.g., storage facilities, and operate the site.

3.2.4 Port of Sines

Among its responsibilities, the Port of Sines Authority (APS) aims at managing, developing, and maintaining the Port of Sines; perform studies and plans within the scope of maritime and land developments and port equipment to be submitted to the Government's approval; to build, purchase, preserve and survey maritime and land developments, as well as the port's land and floating equipment. The company was also endowed the coordination, surveillance and regulating of the activities performed inside its jurisdiction area, without prejudice to the legal attributions bestowed to other companies.

3.3 Identification of existing port platforms and managing parties and entities

3.3.1 Port of Rotterdam

Currently, the port authority does not use any digital tools for monitoring and managing energy consumption within the port ecosystem. Still, the Port of Rotterdam plans to collect data (electricity and fuel use) in port operations by different transport modes. On the other hand, GHG emissions are modelled and simulated based on data provided by port terminals and industrial entities.

In the domain of green logistics, the Port of Rotterdam utilises the following platforms:

Portbase[24] is a Port Community System (PCS): a digital platform that aims to integrate Dutch ports and their respective actors. Such integration is related to the exchange of data across the logistic chain. Several services are available, e.g., pre-notification of calls and containers for the hinterland, scanning and physical inspections

PortXchange[25] is a platform that allows for the exchange of information about port calls across entities like shipping companies, port terminals, transport service providers, and the like. Each vessel can be tracked on regards to the several events during the port call as soon as the Estimated Time of Arrival (ETA) is known.

Routescanner[26] is a platform that allows customers to find an optimal, sustainable intermodal route for transporting containers by aggregating schedules from transport operators and information about ports. The platform allows sorting the results by criteria related to lead time, emissions levels (in kg CO_2e/TEU), and the like.

Nextlogic[27] is a platform, currently under a test pilot, which allows the integrated planning of barge operations, by allowing the exchange of information between barge operators, skippers, depots, and terminal operators. For instance, terminal operators and depots can provide information about the available capacity, which is used to aid planning of the arrivals and departures of barges. The Portbase PCS acts as the medium through which such information is exchanged.

3.3.2 HAROPA PORT

HAROPA PORT launched the TRAFIS LAB35, an applied research laboratory for the facilitation of trade and the development of digital logistics, in response to new opportunities in international trade. Together with the Le Havre Normandy University, SOGET (a software publisher company) and ISEL (Institut Supérieur d'Etudes Logistiques), HAROPA PORT initiate in 2017 a Scientific Interest Group (GIS) to host an innovative public-private partnership. The laboratory will welcome researchers and professionals from all over the world. The ambition of this GIS is to design complete and competitive solutions for increasingly efficient port and logistics passage. The founding members want to prove that port efficiency, the relevance of the supply chain and the responsiveness of its players are determining factors of attractiveness.

[24] https://www.portbase.com/en/
[25] https://www.portofrotterdam.com/en/services/online-tools/portxchange
[26] https://connections.routescanner.com/rotterdam
[27] https://nextlogic.nl

As part of the Smart Port City programme, the 5G LAB36 was formed with collaboration of the Urban Community of Le Havre, the Port of Le Havre, and another three companies: Nokia, Siemens and Électricité de France (EDF). The objective is identified application scenarios that could, after some experimentation, be developed across the Seine Axis ports. Among the first application scenarios that have been identified there is the optimisation of upkeep operations for the port's navigational areas: the implementation of 5G would notably provide improvements and greater safety for the daily dredging campaigns in the channels and docks.

HAROPA PORT has also been developing its own digital revolution with the smart corridor 37, which makes Le Havre, Rouen and Paris connected, innovative and collective ports, constituting an innovative port corridor to improve the quality of services for customers and territories in a sustainable way. The port of Le Havre had already invested in SOGET, which was developing one of the first Port Community Systems (PCS), a software program to streamline procedures related to freight transport operations. PCS is also an open, neutral digital platform that enables real time exchange of information between public and private organizations in logistics, port and airport chains, including transport organizers, air freight and shipping companies, logistics and customs warehouses, customs brokers, terminals, customs and administrative authorities responsible for foreign trade, safety and security bodies, port and airport authorities, and government departments. With this partnership was launched the S)ONE38 platform. S)ONE is SOGET's fourth-generation PCS. The modular platform was developed using the latest Microsoft technologies offering many additional services to further optimize logistics chains. It is an opportunity to automate and digitize the administrative, logistics and commercial processes required for goods transit. The platform main goals are reducing transit time for goods by simplifying and automating business processes and securing information in accordance with international standards.

3.3.3 DeltaPort

DeltaPort does not have any DTs for supporting logistics operations, energy consumption and emissions. The platforms used by transport operators and logistic service providers are do not allow for an integrated exchange of information. Therefore, links between partners in the transport and logistic chain are less developed.

The container terminal operator Contargo uses the tool MODALITY for various applications of terminal operation. The tool WEBFLEET is implemented by Contargo for the management of truck operations, which includes real-time tracking of the location of trucks. Support for synchro-modality is envisaged by the Contargo Logistics App (COLA). COLA is the digitalisation project of Contargo that aims to integrate the platforms used by each actor over the port ecosystem. For the Rail Gate a CAMCO application has been implemented.

For intermodal transport, efficient planning and scheduling are key requirements. DeltaPort has an important function for the coordination of transport modes. Moreover, transport operation needs to be linked with port operation and logistic services. Real-time information and data exchange between partners in the transport chain facilitate the coordination, in particular in the hub. Digital tools contribute to efficient planning and management, but the capabilities depend on data availability and exchange between partners.

3.3.4 Port of Sines

APS promoted the digitalisation of all the processes within its logistics chain by implementing the Logistic Single Window (LSW), in cooperation with other Portuguese ports. LSW is a national system that supports all the operations in the port, including the movement of goods by the different means of transport.

That information system allows collaboration and data sharing between ports and will be the main source of data for the new products and services of Nexus agenda (Section 2.4).

LSW, JUL in Portuguese Language, is a natural evolution and extension of the Port Single Window which extends the management of information flows throughout the logistics chain, simplifying and dematerializing procedures, to all means of land transport and in connection to national and Spanish dry ports to Madrid. It is intended to ensure the flow of information regarding the transport of goods to and from national seaports.

3.4 Mapping of services/assets and platforms

3.4.1 Port of Rotterdam

The Port Authority already has a digital twin for monitoring maritime conditions, namely tides and water conditions. Besides the digital platforms described in 3.3.1, the Port Authority aims to exploit the use of semantic models, e.g., ontologies, to facilitate the integration of heterogeneous data from multiple sources, and ultimately represent several assets that relate to port operations, e.g., quay cranes, trucks, and the like.

3.4.2 HAROPA PORT

Regarding energy consumption, working groups are regularly organised between HAROPA PORT, RTE and ENEDIS on the monitoring of consumption of port stakeholders. The granularity of data is variable, usually monthly, as there is no fixed frequency for such meetings. RTE and ENEDIS own such data.

GHG emissions are monitored, analysed, and assessed. A reporting of GHG emissions is legally due every three years. The first official report for HAROPA PORT is in the course of being prepared for the year 2022, to be disclosed in the upcoming months. In terms of future internal process, the collection of GHG data across the different HAROPA PORT services will be done annually with a revision of the actions plan every three years, after the finalisation of the reporting. Among the GHG-emitting sources, this is on which categories the data is collected:

- Direct GHG emissions.
- Direct emissions from stationary combustion sources.
- Direct emissions from mobile heat engine sources.
- Direct process emissions (excluding energy).
- Direct fugitive emissions.
- Emissions from biomass (soils and forests).
- Indirect energy related GHG emissions.
- Indirect emissions related to electricity consumption.
- Indirect emissions linked to the consumption of steam, heat or cold.
- Energy-related emissions not included in the previous categories.
- Upstream emissions from heating + upstream emissions related to dredger fuel.
- Purchases of products or services.
- Business trips.
- Transportation of visitors and customers.
- Other indirect emissions.

3.4.3 DeltaPort

In the transport and logistic domain, the coordination of port/terminal handling, various transport modes and logistic services is important. Digital tools of transport operators (see above) address these interfaces and contribute to seamless intermodal transport. This covers in particular pre-arrival information, e.g., of vessels, such as the ETA (Estimated time of arrival) and information on the cargo for the preparation of port/terminal operation and following processes. Following processes may include intermediate storage, onward transport and logistic services.

Planning and real-time management would strengthen the performance and the efficiency. The project "Event Driven Process Stimulator" aims on an automatic pre-notification of vessel arrivals at DeltaPort. The pre-notification should allow to better plan and prepare cargo handling and following processes. Preparations may refer to the personal resources, storage capacities and onward transport capacities.

3.4.4 Port of Sines

The following modules of the LSW (JUL) that support the services provided by the Port of Sines have been operational since September 2021, namely:

- GEN (Ship Schedules Management) - management of the ship call, allowing its creation, the presentation of declarative acts related to the mean of transport and goods and obtaining authorizations for the ship to enter and leave the port.
- GDM (Manoeuvrer Management) - management and planning of manoeuvres, allowing the recording of resources used, including piloting, towing, and mooring. Record of rall ship movements, with the possibility of integration with the Vessel Traffic System.
- GSU (Services and Utilities) – management of all services requested within the scope of a ship call or other context. It includes service requests, responses, and the respective execution record, when applicable, for later billing.
- GTF (Rail Transport Management) - management of the train calls, with recording of train timetables and locations.
- GTR (Road Transport Management) - truck handling management, with registration of train calls.
- GAS (Gate Appointment System) – makes available to Road Transport Operators the scheduling of delivery and collection of containers, in line with the capacity and time window of the Terminal Operator or Logistics Platform.
- CUP (Accreditation System) - request, approval, accreditation, and access control process in all areas of the port, with simultaneous validity for the Border Authority, Maritime Authority and Port Authority and Port Facilities.
- GOS (Gate Operating System) – registration of movements on road and rail gates, through validation of means of transport, drivers, and cargo.
- TOS (Terminal Operating System) - planning and executing the movement of containers, their loading/unloading and storage in the park.
- SPA (Security Management) - management of safety, security, and environmental inspections.
- GPA (Customs Processes) – management of customs authorizations for container movements.
- GIP (Inspection Management) - management of phytosanitary inspections on containers.

- FDA and FAT (Invoicing) – process of automatic validation on the conformity of ship calls, and pre-invoicing of services in the scope of that call, applying the tariffs of the port/port facility and other entities that provide the services. Integration with an external ERP system.
- MSG and MNC (Messaging System) – processing, monitoring and control of messages exchanged between stakeholder's information systems and LSW.
- GAD (Access Profile Management) - management of entities, access profiles and users that interact with each application/module on the LSW.
- EST (Statistics) – production of official statistical reports, for national entities/authorities, indicators, and operational reports.

APS is working with other partners on the development of digital platforms to help managing the planning, scheduling, and management of physical and non-physical port assets. For instance:

The Multimodal Control Tower will provide end-to-end tracking of the logistics flows in the network, across all transport modes, including performance assessment of transport services.

The Haulier capacity matching optimiser will promote the efficient allocation of available road transport capacity, when dealing with pick-up and drop-off of cargo from maritime terminals.

The AI powered Container Freight Stations will promote the intelligent consolidation of cargo in Container Freight Stations according to the transport selected for the next leg, supporting the consolidation and deconsolidation of containers, palletizing, or packaging to ensure high velocity operations and optimize the costs for transport operators.

The Advanced Dry Port operations platform extends the capabilities of traditional Terminal Operating (TOS) systems, to include: blockchain based paperless procedures with authorities; automated virtual gates with AI powered decision making; and optimised rail handling and yard operations.

The Smart Gates Solution for Ports will be a full suite of automation for gates at sea terminals covering road and rail operations. It will use the collaborative data to develop predictive models and Machine Learning to further enhance sychromodal operations.

The Smart Mobility Management will be an advanced algorithmic tool for scheduling operations at logistic gates, based on historical information, and on real-time data collected through multiple sensors and fed from the open data collaboration platform.

The Cloud 4 Access Control Solution will be an access control, security, and surveillance platform, suitable for complex operation facilities, such as ports and logistics terminals, with embedded threat predictive capabilities.

The 3D Smart Depot Panel will be a Container Stacking Planning and Visualisation Tool for Depots with an innovative UI/UX. It is presented as an add-on to TMS or TOS systems, with interfaces that allow reading the real-time information of the depot\terminal state.

A Port Scene Analytics solution that will use image recognition techniques and AI to perform digital environment analysis of elements and abnormal behaviour in Logistics Areas, perform automated container code recognition, detect damage in containers, and automated recognition of the type of cargo.

The Performance Management Sea & Dry Ports makes it possible to collect data from port and/or logistics operations to measure and identify points of improvement that allow for the optimization of resources, cost reduction and energy savings.

The Smart Berth Planning will optimise berth planning, by incorporating predictive analytics and take advantage of all the collaborative data available from other stakeholders in the network to significantly improve decision making.

The Connected Driver Advisory System is a digital solution to support and advise the driver for the best train driving strategy based on the analysis of various parameters, such as train composition type, train load, profile of the line where it circulates, schedule, dynamic constraints occurring in the infrastructure, crossing with other trains. It will allow train operations to optimise energy efficiency while decreasing GHM emissions.

The Smart Train Solution will establish a solution that includes software services and proprietary sensor devices that collect performance, safety, logistics and energy efficiency data, to explore IoT and Big Data Analytics in freight train operations.

The Train Capacity Management Solution will support operational alignment between train operators, terminals and dry ports and freight forwarders.

The NEXUS WebTrans is an innovative Transport Management LowCode\NoCode framework to build cloud apps that will be integrated with NEXUS, and manage natively eBL, eCMR and all eFreight documents.

The NEXUS eBL will be an interoperable Blockchain platform for dematerialization of Bill of Lading documents using blockchain technology following the international trade standards.

The NEXUS eCMR platform will be used for dematerialization of CMR documents using blockchain technology, that can be plugged-in to other eCMR solutions (not based on blockchain).

The Shipping on Time will be the solution for the booking and management of containers transportation on land between the shipper and port (export) and port and consignee (import), providing visibility/events to the NEXUS open data context (location and expected destination of the container).

The Shipperform will be the solution for transportation and logistics service contracting by shippers allowing multimodal (maritime + road) transportation bidding and booking.

The AI enabled TMS for project cargo, a specialized Transport Management solution for project cargo and special transport that will use machine learning and AI to automate the HR intensive process of planning resource allocation, matching human resources, logistics assets (equipment, trucks, etc) and customer assignments.

A Predictive Transport Radar for cargo owners and transport integrators that provides supply chain visibility. Utilisation of the big pool of data from NEXUS and big data analytics to establish state-of-the-art predictability mechanisms.

The NEXUS 5G Connected Port will be a framework and digital platform, associated with a package of enterprise services, to fully extract Value out of the utilisation of 5G on port and logistics communities. Including specialized Non-Public Network (5G NPN) for Port Communities and Several pre-configured Business cases that require 5G capabilities to be feasible.

The Port and Logistics Energy Management System will be an integrated bundle of products and services that will include: a Digital Port and Logistics Energy Management System (EMS) specifically design for the current challenges of port communities, in the context of the European Commission's Green Deal; several hardware assets that will be directly controlled by the Port and Logistics EMS.

The Green Port and Emissions Monitoring Solution will be an integrated bundle of products and services that will include: a Digital Emissions Control and Monitoring Solution; several hardware assets that will be directly controlled by the digital solution

3.5 Identification of gaps

Some of the participant port authorities already collect data related to particulate matter emissions, even if such data are not retrieved in real time. Still, since most port authorities have adopted a landlord business model with no ownership of the electricity grid, real-time information about energy consumption is either unavailable, or not duly exploited, as they are usually recorded in paper or worksheets (e.g., Microsoft Excel). Given the urgent need for green transition and the double transition effect (see Section 1.1), port authorities could exploit the available information to optimise operations, reduce emissions and energy consumption at the port level, and gain a better understanding about how ports may foster the transition to more sustainable energy vectors.

Other actors of the port's ecosystem, e.g., terminals, road transport operators, already work towards digitalisation of logistics operations and data exchange between actors. However, data are often provided by systems according to non-standard representations, which may hinder they reuse by other platforms. Furthermore, the lack of a knowledge representation model hinders the integration of the several platforms that are used by all actors within the port ecosystem. As an example, fostering sustainable synchromodal operations might be difficult without real-time information made visible to all actors in the supply chain.

Some ports already utilise Port Community Systems and Logistics Single Window platforms to centralise data provided by shipping agents, transport operators, and the hinterland. Still, such platforms currently work as a data hub, in which most data is still provided through human input. Furthermore, such platforms incorporate limited functionalities for evaluating (or implementing) Key Performance Indicators, support decision-making by simulating different operational scenarios or optimising within-port movements towards more efficient and greener operations.

In Table 1, the technologies related to the identified gaps are listed for each participant port and classified according to the level of implementation within each port. The subsequent tasks of WP4 aim to provide the foundation for the application of these technologies, including digital tools, to the future of participant ports and beyond.

Table 1 Overview of the adoption of technologies across MAGPIE ports and the added value of WP4 towards the application of such technologies to foster decarbonisation and green logistics operations.

Use of technology	Port of Rotterdam	Delta Port	HAROPA PORT	Port of Sines	Added value of WP4
Digital Twins	◑ (teal)	◔	◔	◔	Technological components that form a DT for the (non-)physical port assets
Interoperable information exchange between port actors	◑	◑	◑	◑	IDS-like systems architecture for the DT, ensuring secure, interoperable information exchange
Semantics for data integration	◔	○	○	◔	Extendable and reusable domain ontology that models the semantics of port assets
Real-time data to support decision-making	●	●	●	●	A systems architecture built that allows real-time data to be integrated according to an agreed-upon semantic model
Digital tools for decarbonisation	◑ (teal)	◔	◔	◔	Tools for monitoring and simulating emissions and energy consumption levels, according to the UCs proposed by ports and MAGPIE demos
Digital tools for green logistics operations	◑ (teal)	◔	◔	◔	Tools that support the operations of autonomous and electrical vehicles within port areas and the hinterland, according to the UCs proposed by ports and MAGPIE demos

Legend

●	Established use in port operations
◑	In current use for port operations, with limitations on regards to the visibility and exchange of information between port actors
◑ (teal)	In current use as either pilot contexts or small-scale implementation for specific port assets
◔	Not in current use, although there is either interest or plans for implementation.
○	Not in current use; no plans (prior to MAGPIE)

4 Development of the Digital Twin for ports

This section describes the context and approach for developing the technological artifacts that form the Digital Twin (DT) for ports, in particular those related to data representation and exchange. Subsections 4.1 and 4.2 describe the context and scope of the DT (4.1), and the systems architecture and goals (4.2). Subsection 4.3 describes the methodology for developing the semantic model (i.e., ontology) that will allow the integration and validation of data provided by the ports and their external stakeholders. The contents of this section will aid tasks T4.2 and T4.3.

4.1 Context and scope

The Digital Twin encompasses Graphical User Interfaces (GUI) digital tools that must support the decision-making processes of actors of the port ecosystem, and project demonstrators in the context of port operations, with focus on energy systems and logistics domains. Physical assets (e.g., barges, quay cranes) and business processes (non-physical assets, e.g., "unloading of a container") are provided with a digital representation (a model), which is described by means of a knowledge representation model, i.e., domain ontology, which will be developed in tasks T4.2 and T4.3.

The DT allows connecting the port infrastructure, vehicles and assets (e.g., cranes) available to ships, barges, trucks, and trains. Such a connection allows the exchange of information across partners in a secure, interoperable way, whilst ensuring that the underlying data model is acknowledged by the entities that agree on such a data exchange. The DT will facilitate the implementation of autonomous e-barges, e-trucks, and transhipment by acting as a host for the digital link between vehicles and port stakeholders, e.g., port terminals. The following tools will be integrated into the DT:

Table 2 - Digital Tools within the Digital Twin for ports

Digital Tools within the Digital Twin for Ports		
Subtask	Name	Lead Partner
4.5.1	GHG Tooling	TNO
4.5.2	Energy Matching Tool	EDP
4.5.3	Ports Smart and Green Logistics	EUR

A subset of project demonstrators listed below will provide and retrieve data from the DT. The actors involved in each demonstrator will participate in the ontology modelling process, to provide expert knowledge about the practical context and the use cases that the DT is expected to support, e.g., available data endpoints and interaction with digital tools.

Table 3 – Demonstrators to be supported by the Digital Twin

Demonstrators to be supported by the Digital Twin		
Task	Name	Lead Partner
3.8	2 – Smart Energy Systems	EUR
3.9	3 – Shore power Peak Shaving	TNO
5.3	6 – Autonomous e-barge and transhipment	POR
6.2	9 – Green Connected Trucking	TNO
6.3	10 – Spreading Road traffic	POR

The following actors will benefit from the DT and will participate in the subsequent requirements elicitation process and evaluation of the technological artifacts to be developed in tasks T4.2 and T4.3:

- Port authorities
- Port terminals
- Shipping agents
- Truck and barge fleet owners
- Research Institutes

The DT must be built upon a secure and interoperable medium for data and information exchange, since part of instance raw data will be retrieved from actors that possess data that is decentralised and sensitive to their business activities. The need for different levels of data protection require that the underlying systems architecture ensures data sovereignty whilst allowing that just the right data instances are exchanged between MAGPIE partners and, more generally, port stakeholders.

Figure 7 depicts the DT as a ring that provides the technological infrastructure to allow the interoperable, secure exchange of data between various nodes. Each node represents either a port authority, stakeholder, or a MAGPIE digital tool. Within a node, several (sensitive) data endpoints exist, each providing data with various syntax (e.g., CSV, XML, JSON) and schema (e.g., EDIFACT standards). The underlying semantic model, which is part of the DT, will ensure the integration of such heterogeneous data sources.

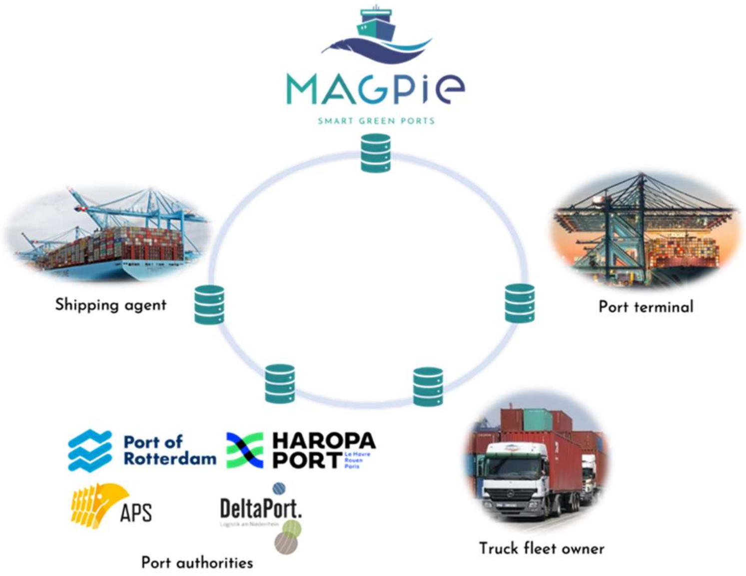

Figure 7 – The Digital Twin for ports connects port stakeholders and orchestrates digital tools to enhance decision-making. Such tools depend on heterogeneous data scattered across such stakeholders (nodes).

A set of desired high-level goals for the Digital Twin was agreed-upon at regular meetings and the WP4 workshop, which are listed in Table 4:

Table 4 – High-Level Goals for the Digital Twin

HIGH-LEVEL GOALS FOR THE DIGITAL TWIN	
Goal	Description
1	The DT must support MAGPIE demos 2, 3, 6, 9, and 10 on showcasing the potential of automation and port digitalization towards zero-emission, energy-efficient operations.
2	The DT must support the integration and management of instance data retrieved from the port and external stakeholders through a secure and reliable data management infrastructure based on a Data Space reference architecture.
3	The DT must allow planning and designing the green energy carrier infrastructure, and validate it against the port's logistics demands, through a simulation environment.
4	The DT infrastructure must support the real-time orchestration of the different transportation models and algorithms for operations planning and scheduling, towards a synchro-modality approach.
5	Digital representation will bring together the port's infrastructures, orders, and operations with the port's modalities (e.g., trains, ships, barges, and trucks) to provide a holistic view over the port's multimodality and logistics.
6	The semantic model of the DT must model the physical and non-physical assets of the port ecosystem, in particular their energy and GHG emission behaviour.2

4.2 Conceptual systems architecture of the Digital Twin

The backend of the Digital Twin will be developed by the partners involved in tasks T4.2 to T4.5, using, for instance, Reference Architecture models for International Data Spaces (IDS-RAM), to ensure that data is shared across the actors of the ports' ecosystem in a voluntary and secure manner[28]. For each "node", i.e., digital tool and data endpoints, an IDS connector will be implemented, featuring services for data processing, and data format alignment. All actors will be able to interact with the functionalities of the DT by means of a graphical user interface frontend that orchestrates the interfaces of digital tools, including the visual representation of the outputs that they provide, e.g., by means of interactive dashboards.

To ensure interoperability, a vocabulary provider will be implemented[29], featuring the domain ontology to be developed within the project, as well as auxiliary ontologies. The interoperable data will be represented as an RDF knowledge graph. Due to the modularity of the DT, other digital tools can be incorporated, provided that the data exchanged between the tool and the DT can be mapped onto the ontologies contained in the vocabulary provider. The first version of the modular architecture specification of the DT will be delivered by M18. Such a specification will describe the modules that the domain ontology (Section 4.3) should encompass to support the use cases that were identified in Section 5.

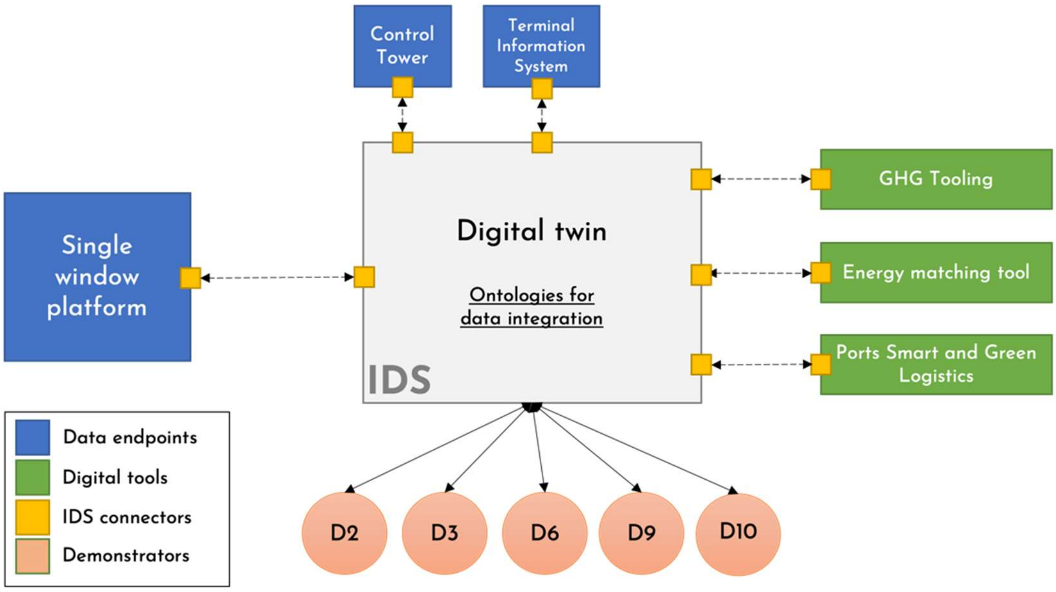

Figure 8 – The conceptual system architecture for the Digital Twin will follow the International Data Space Reference Architecture (IDS-RAM). The information layer will encompass a domain ontology developed within the scope of MAGPIE. IDS connectors will allow the interoperable, secure exchange of data across port entities and external stakeholders.

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[28] IDSA Reference Architecture Model 3.0. URL: https://internationaldataspaces.org/use/reference-architecture/

[29] van den Berg, W., Stornebrink, M., Stoter, A., Wijbenga, J.P., "The Vocabulary Hub to configure data space connectors" (2022), Available at: https://www.trusts-data.eu/wp-content/uploads/2022/06/04_TNO-april-2022-The-Vocabulary-Hub-to-configure-data-space-connectors.pdf

4.3 Development of a domain ontology for ports

The DT platform will allow for the exchange of interoperable data across the port and external stakeholders, as described in Sections 4.1 and 4.2. Such data is heterogeneous by nature, which pose conceptual and technical challenges for data integration and manipulation. A domain ontology for ports will model the constructs related to the domain of green energy systems and logistics.

Ontologies are formal and unambiguous models that capture the semantics of a domain of knowledge[30]: its concepts and relations. Combined with semantic technologies, ontologies provide the foundation for integrating disparate data sources, so that it can be understood by humans and machines; an extensive description of semantic heterogeneity types can be found in reference below[31].

Tasks T4.2 and T4.3 will adopt, with some flexibility, the guidelines of the IDEF methodology as it is concerned not only with the creation of ontologies, but with their further modifications[32]. As we expect our ontology to be used in different contexts, we argue that the choice for this methodology is sound. In brief, the methodology comprises the following activities:

- Organisation and scope definition: the identification of the purpose and context of the ontology.
- Data collection: the acquisition of domain data needed for the development of the ontology.
- Data analysis: the definition of which elements of the data collection are necessary to be present in the ontology.
- Initial ontology development: a prototype of the ontology in which the preliminary validations are made.
- Refinement and validation: application of tests with real data.

The ontology is expected to be built in OWL according to a top-down approach, i.e., upper classes and properties will be defined and further refined. The first conceptualisation of the main domain ontology constructs will be delivered by M20; subsequent iterations will be performed as the development of the use cases progresses throughout the demonstrators and digital tools developed within WP4. During the process of ontology development, competency questions will be defined, i.e., requirements in the form of structured questions that the ontology should answer. An example of competence question is "Which attributes characterise the trajectory of a barge?". An initial set of competency questions[33], as well as a semi-structured interview guide (see Annex 2), were prepared as a first attempt to retrieve domain knowledge from port stakeholders and other project partners. Such artifacts will be used throughout tasks T4.2 and T4.3.

[30] Mohammadi, M., Hofman, W., Tan, Y.H., "Seamless interoperability in logistics by ontology alignment" (2020). Journal of Supply Chain Management Science. DOI: 10.18757/jscms.2020.5444
[31] Bergman, M. K., "Big Structure and Data Interoperability" (2014). URL: https://www.mkbergman.com/1782/big-structure-and-data-interoperability/ (accessed Oct. 1st, 2022).
[32] Knowledge Based Systems, Inc., "IDEF5 – Integrated Definition for Ontology Description Capture Method" (1994). URL: https://www.idef.com/idef5-download/
[33] Developed by TNO

5 Preliminary definition of data needs and functional requirements for the DT and the digital tools

This chapter describes the use cases that have been developed so far within Task 4.1., which are being used to further detail to the high-level requirements (Table 4) for the digital twin (DT) and tools. The main approach includes the selection and characterization of several use cases describing the role of the DT and the digital tools (GHG, energy matching, green and smart logistics) in the port ecosystem. These cover a range of instances that represent the way the DT and the digital tools will be used by the ports' stakeholders at different levels of implementation. First, cases that represent the potential use of the DT/tools at a higher level of operation, spanning one or several terminals, and eventually the full ecosystem of ports. Second, the use of the digital tools within various scopes and the expected links to the DT. And third, to represent the use of the digital twin and tools at the level of the MAGPIE demos. The description of the use cases is still ongoing, with the description of the demo level use cases only having kicked off in M12 and a preliminary full description is expected at the end of M20 (with the delivery of the ontology in T4.3). Since the first version of the digital tools and the DT is only expected in M30 (as per the plan in the Grant Agreement) the description of the UCs will be further revised and refined until M30.

5.1 Use cases at port/terminal level

5.1.1 Logistical model for hinterland transport between Port of Rotterdam and Delta Port

Objective

Support the development of models for sustainable synchro-modal transport in hinterland connections (Task 6.4), to explore opportunities related to hinterland transport between the Port of Rotterdam and the catchment area of DeltaPort. The main aim is to strengthen inland waterway and rail in hinterland transport by increasing cost-efficiency and reliability to reduce emission in hinterland transport through a modal shift. Namely, the seamless coordination of modes and the efficient transhipment and handling of cargo in the hinterland hub DeltaPort are essential for the modal shift from road to inland waterway and rail.

The models will address the synchromodal optimisation of modes, planning of port operations, coordination of modes and optimisation of last mile operation. Based on logistic structures, DeltaPort will also explore opportunities for the use of alternative fuels such as hydrogen. Various components of the hinterland supply chain with DeltaPort as hinterland hub in its core would need to be modelled. For the modal shift in the last mile, the extension of inland waterway and rail operation towards the hinterland and the implementation of secondary hubs are considered. Additional to truck operation in the last mile, the use of innovative last mile vehicle shall be investigated. The concept builds on the Log4NRW project.

Market parties/stakeholders involved

Various partners are involved in hinterland transport. Actors include:

- maritime shipping lines,
- freight forwarders,
- terminal operators,

- transport operators (IWT, rail, road) and
- shippers.

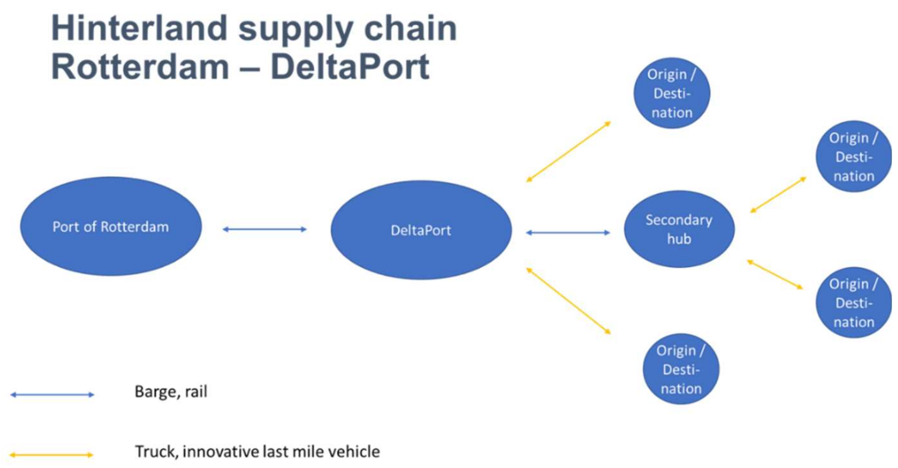


Figure 9 – Logistical model hinterland transport

Links to Digital Twin (I/O)

Digital tools (such as the Event Driven Process Stimulator (EDPS)) and platforms are important elements to facilitate data exchange and materialise information to strengthen hinterland transport. Depending on the data coverage and exchange of information between partners, digital applications can improve the coordination of hinterland transport partners. For instance, notifications on the ETA (Estimated time of arrival) allow to better plan following processes (port, terminal, transport, logistic etc.). More advanced digital applications may strengthen management capabilities to optimise hinterland route, modes etc. with respect to the real-time situation.

The availability of real-time information and the exchange between partners facilitate the coordination of hinterland transport. This includes the pre-notification of cargo and the planning of port/hub operation, cargo handling, onward transport, last mile transport and other logistic processes. Moreover, real-time information on delays and interruptions may lead to the adaptation of planning regarding route, modes etc.

Apart from basic data on the cargo (commodities, volumes, logistic requirements etc.) and the transport route, information on the processes (transport, transhipment/handling etc.) are required to improve the coordination of the various interfaces. For advanced real-time planning, digital tools require additional data such as information on available capacities (terminals, transport modes etc.) and traffic situation.

Data Flow

The EDPS aims to provide an automatic notification function for approaching vessels well before arrival in DeltaPort. Based on the AIS signal, a notification is sent when the barge passes a pre-defined geofencing grid. Various grids could trigger different follow-up processes depending on the required lead time for following processes. Upon notification preparation of following processes will start and allow more efficient operation of port, terminal, onward transport etc. This will be implemented through a link with transport management systems (TMS) of operators.

5.1.2 Integration of renewable energy supply in Ports

Objective

Development of an energy optimization tool that will allow the deployment and integration of renewable energy and sustainable supply systems such as solar PV plants or wind turbines within European ports. As renewable energy is variable, dependent on weather conditions, storage systems may aid in the management of the energy supply chain that powers all port asset, connected also to the port electricity grid.

The optimization of the system will be based on the following two main objectives: minimization of GHG emissions and costs (OPEX and CAPEX). The tool will rely on a predictive control model (PCM) and an objective function that will take into the precious objectives, which will rely on translating CO_2 (or all GHG if possible) emissions into operating expenditures. This will be made by following the emissions price in the European Union, which is currently near 90€/tCO_2 [34].

To manage the different energy supply sources with the PCM, information/models of the flexible assets in the port (or terminal) energy system will have to be known/developed. It is assumed that the port authority/terminal operator will be able to choose among storing the PV generated electricity into battery energy systems, using it for charging operations (e.g., e-trucks, e-barge) and transforming renewable electricity into green hydrogen to be stored. The rest of the port activities are assumed to be supplied by wind turbines or directly from the electricity grid. The main decision making is related to the choice of using energy storage systems of any kind, considering the power grid and potentially buildings that have heating and cooling needs, but could have delayed or advanced consumption based on availability of local renewable electricity.

Market parties/stakeholders involved

Ideally the tool should be used over the whole port ecosystem. However, due to potential limitations in data availability, the scope of the use case will be a container ship terminal in the port Le Havre. This choice assumes that all the services in the terminal are included, and this terminal is completely independent of the rest of the port.

The parties that are involved in the use case are:

- Port Authority
- Terminal operators
- Transport operators (IWT, rail, road)
- Shippers
- Energy infrastructure operators
- Other actors.

[34] 2022-August-26 on https://carboncredits.com/carbon-prices-today/

Links to Digital Twin (I/O)

The PCM model requires numerous input data. A working list of the type of services, systems, and components to be modelled and input data is provided in Table 5 and Table 6, respectively.

Table 5 - Systems and components to be modelled/represented

Service	System	Component
Energy production	Several: Wind/solar farm, H_2 production	Several: PV panels, inverter, turbine, electrolysers, steam reformer, compressors, H_2 storage, evaporator
Power supply	Several: Wind/solar farm, electricity grid, Onshore Power Supply (OPS)	Several: PV panels, inverter, wind turbines, electricity delivery node
Energy Storage	Stationary storage systems	Battery EES, Embedded Battery
Charging	Electricity grid	Delivery point
Carriage into/from port	Rail (freight), truck, barge, tug, other IWT vessel	Engine, charging point, fuelling station
Haulage onto port	Forklift, crane	Engine
Selling to energy grid (e.g., flexibility, demand response)	Building, warehouse/shed	Air handling unit, boiler, heat pump, other heating/cooling system
Refrigeration	Cooling container, REEFER	Compressor
Stowage/lashing	-	-
Lighting	-	LED, other lighting systems

Table 6 - Data parameters per service, system, and component

Surrounding data	Per Service	Per System	Per Component
Spot price of grid electricity	Schedule of service / landing	Energy capacity	Power rating
Re-selling price of energy	Energy needs (type, quantity and typology)	Energy demand	Type of fuel
Fuel prices	Priority	Efficiency	Fuel consumption
Contract for electricity (energy and power)		Energy use profile	Efficiency
		DB of units	Battery capacity
		Unit price	Charging and discharging currents
		Coverage rate	Storage capacity
			DB of units
			Unit price

The model will calculate the optimisation path, for instance, every 6 hours according to the evolution of activity schedule in the port terminal, the periodic update of the production forecasts, and the discrepancies observed between the different state predictions and the registered measurements.

Data Flow

The predictive control model requires linear or MILP (Mixed Integer Linear Programming) models for each element of the energy system, including production and storage facilities, connection to the electricity network. It also entails forecasting operations of weather conditions or energy productions. The time step will be defined from a few minutes to 1 hour. The PCM will operate continuously and its outcomes, corresponding to the state of the different energy component (levels, health, productions, availability) will be loaded and compared with the data measurements of the real system data (digital twin), whose continuous recovery will be triggered by the port DT as defined/implemented in T4.2/4.3.

5.2 Use cases describing the scope of implementation of digital tools

5.2.1 GHG emissions tool

Objective

The aim of the GHG emissions tool is to establish a standardized measurement procedure to calculate and allocate CO_2 and other GHG emissions in transport chains that go via the Port of Rotterdam. By using primary data (i.e., real-world observed emission data) as much as possible, the GHG emissions tool will develop modelling and prediction capabilities to facilitate emission reduction at different level, providing, at operational level, the least polluting option in terms of efficiency, fuel shift, modal shift and route choice. The GHG emissions tool will also work at a strategic level, providing an evidence-based analysis of the impact of innovation and policy measures.

Computations will be performed in accordance to the EN16258 Standard and will be compliant with the new ISO 14083 Standard.

The final product that will be delivered will contain the following:

- Real-world data on transport chain emissions related to the port
- Emission-relevant data exchange through safe data-exchange mechanism
- Decision support tool for decarbonisation at operational level
- Modelling software for what-if scenario assessment

Market parties/stakeholders involved in the tool

The parties that are involved in the GHG emissions tool are:

- Port Authority
- Truck/train/barge/ship owners and operators
- Shippers
- Terminal operators
- Freight forwarders
- Energy infrastructure operators
- Other actors involved in transport supply chains.

Links to Digital Twin (I/O)

The GHG emissions tool will be used by shippers to select the greenest transport chain and initiate a modal shift. The tool will also be used to evaluate the impact of future green energy solutions for transport. The GHG emissions tool will develop modelling capabilities related to international shipping and hinterland transport, operation of hubs and terminals.

At the operational level, the GHG emissions tool will combine transport costs, transport operational data and the GHG emissions (and their implied monetary value) into one multi-criteria utility value to aid decision making. A typical choice set at the operational level is the modality choice for hinterland connections, the choice between different service providers and carriers, operational routing of the containers through hinterland terminals. Therefore, at an operation level it is expected that the GHG emissions tool will be used by shippers and truck/train/barge/ship owners and operators to select the greenest transport chain and initiate a modal shift.

At the tactical level, GHG emissions information will be used to facilitate choices related to mid-term performance, such as annual contracting, planning of operations with a planning horizon of a maximum of 3-5 years. This may involve facilitation of the annual service contracting, assessment of the plans of service providers and their impact on the scope 3 emissions of the parties that use those services, including ports. At this level, impact of tactical adjustments in the processes and collaboration structures will be assessed.

At the strategic level, modelling will provide the port with the capability to assess the impact of autonomous trends on GHG emissions and to evaluate the effect of decarbonization measures together with trends beyond the control of stakeholders. Assessment and prioritization of long term or capital intensive projects will be the primary focus of this level. Therefore, at a tactical and strategic level it is expected that the GHG emissions tool will be used by universities, research institutes, green fuel and engine developers to evaluate the impact of future green energy solutions for transport.

Data Flow

The data flow for the GHG tool is currently under development, and a full description is expected before M30. Different actors (e.g., port authority, shippers, freight operators, terminals) will be contacted and involved in the identification of how, what type and when data will be exchanged between the different actors. This information should be detailed enough to allow a comprehensive description of the data exchanges for the relevant logistics processes needed for full GHG mapping of the transport chains. Not defined yet.

5.2.2 Energy Matching Tool

Objective

The main objective of the Energy Matching Platform (T4.5.2) is to match the supply and demand sides that co-exist in a port ecosystem. In other words, the tool will ensure power system balance while considering all the system constraints. While ensuring it, different objectives can be pursued such as minimizing the operational costs of the system, maximizing the RES penetration, etc. Final decision concerning the objective function of this optimization platform will depend on discussions with port authorities and other relevant port stakeholders.

Market parties/stakeholders involved

The involved market parties/stakeholders are deeply associated with four segments that are crucial for the energy matching platform: 1) Electrical grid; 2) Demand; 3) Energy Sources; 4) Battery Energy Storage Systems (BESS). Figure 10 provides a full list of potential market parties/stakeholders with whom the Energy Matching platform will need to establish data exchange procedures (via the Digital Twin). On the demand side, several different stakeholders can be identified: terminal operators, e-charging station owners, H2 producers through electrolysis, industrial stakeholders. Also, on the supply side the involvement of different stakeholders might be necessary, namely RES & Conventional Generation unit's owners.

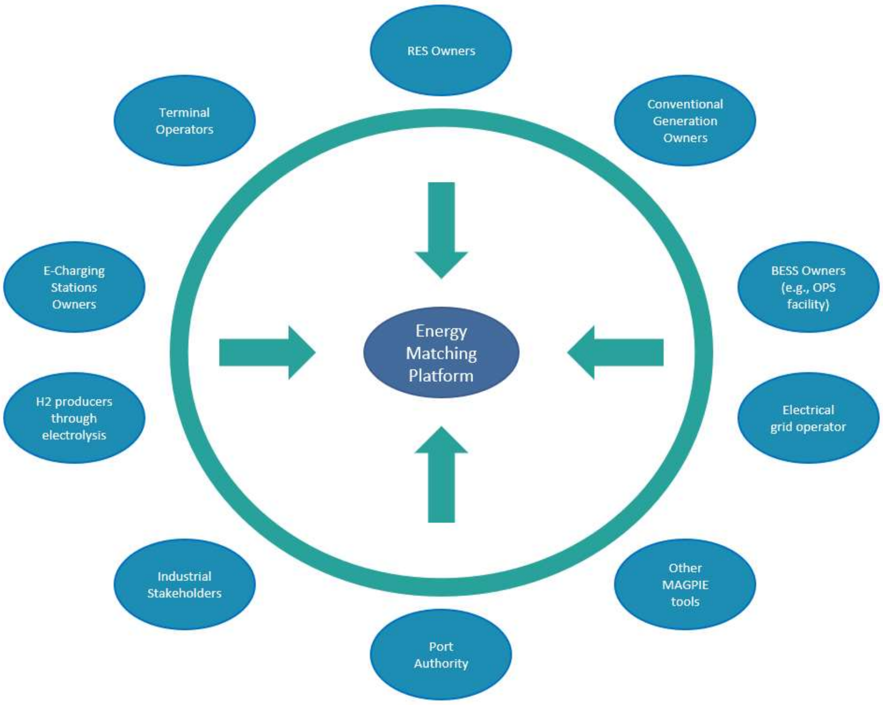


Figure 10 – Market parties/Stakeholders & The Energy Matching Platform

As previously mentioned, this is an extensive and complete list of potential stakeholders. However, the link between them and the Energy Matching tool might not be necessary depending on some decisions that, at this moment, were not yet taken. A good example is associated with the demand side where information just at an aggregated level might be needed. This means that demand values could be obtained directly from the substation metering and no need of disaggregated information per each demand source (e.g., each equipment within a terminal) would be necessary. In that case, and much probably, the grid operator would be able to provide such input and the link with the terminal operator could be neglected. Other good example regards to the electricity grid topology. Depending on the port, this information might be owned by the port authority itself or by the distribution grid operator. Since several other examples like this might exist, it is not yet possible to define a final list of stakeholders.

Important also to mention that the Energy Matching platform will require a link with the models that are being developed in T4.4 and that will provide day-ahead forecasts for the demand and supply sides. Other connections with the remaining digital tools might also be needed (still under investigation within WP4).

The Energy Matching tool intends to work on two different timeframes: 1) Day-ahead; 2) Near real-time. The fulfillment of 1) is dependent on T4.4 forecasts while 2) strongly depends on the availability of real-time measurements from the different demand/supply sources. In case these inputs are not available, the tool performance might be tested based on the long-term energy scenarios being developed in WP3. Discussions if the information that compose such scenarios might (or not) be exchanged through the Digital Twin will be necessary.

Connection to Digital Twin (I/O)

The list of inputs required by the Energy Matching tool are presented in Table 7. The considerations need once again to be considered. As an example, multiple data owners might possess the same information. The decision of who will be the final responsible to provide such inputs is still not finalized.

Table 7 – Inputs for the Energy Matching tool

Input	Data Owner
Grid topology and electrical characteristics of all components (e.g., transmission lines, transformers; generating units; BESS)	NL Distribution System Operator; Port Authority
Hourly Generation Measurements	NL Distribution System Operator; Port Authority; RES Owners; Conventional Generation Owners
Hourly Demand Measurements	NL Distribution System Operator; Port Authority; Industrial Stakeholders; H2 producers through electrolysis; E-Charging Stations Owners; Terminal Operators
BESS State-of-charge	NL Distribution System Operator; Port Authority; BESS Owner
Hourly Generation / Demand forecasts	T4.4
Supply Chain sizing*	WP3
Long-term energy scenarios*	WP3

* Inputs needed in case the Energy Matching tool is going to optimize future energy scenarios

Concerning the outputs, the Energy Matching tool will provide a list of control-actions for different flexible port assets (e.g., BESS, flexible loads). If implemented, such control-actions will allow to accomplish the tool main goal: match supply and demand while ensuring a stable operation of the electrical grid and by fulfilling a specific objective e.g., minimization of the operational costs.

Table 8 – Output retrieved by the Energy Matching tool

Output	Data Receiver
List of control-actions	Port authority; 3rd party assets (RES owners, Terminal Operators, etc)

The Digital Twin will be responsible for ensuring that the Energy Matching tool can access the required inputs. To do so, dedicated API end-points should be made available by the Digital Twin so that the Energy Matching tool can submit the respective queries. On the other hand, the results of the Energy Matching tool will be made available to the end-users through a dedicated API that will be built from scratch during the MAGPIE project.

A successful link between the Energy Matching tool and the Digital Twin lies on an effective answer to the following questions:

- What are the characteristics of the different elements that compose the electric grid (e.g., transmission lines, transformers; generating units; BESS)?
- What is the current status of the electrical topology?
- What are the current active power measurements of Demand/Generating assets?
- What is the State-of-Charge of BESS?
- What are the Load/Generation forecasts for the next 24h?

Data Flow

Concerning data flow requirements, a bidirectional flow between the Energy Matching tool and the majority of stakeholders will probably be needed. There is no doubt that all the stakeholders involved with the grid, demand, supply and BESS sides will need to provide inputs to the Energy Matching tool. However, it is not yet decided if the control-actions provided by the tool will be implemented on site, which would lead to a bidirectional flow of data. Regarding the connection between the Energy Matching tool and the remaining digital tools being developed in WP4, a unidirectional flow of data is expected to be established.

The Semantic Model

The inputs required by the Energy Matching tool (Table 1) are all associated with the electricity supply chain e.g., grid, loads, RES, etc. The different attributes that characterize each of these elements are already well defined in another ontology - the Common Information Model (CIM). In that sense, the characterization of electrical elements should use as basis the attributes followed in the CIM.

Concerning the list of control-actions (outcome of the Energy Matching tool) the following attributes should be enough to characterize it.

Table 9 – Attributes to characterize the output of the Energy Matching tool

Feature	Data Type	Description
Node Id	Integer	Unique identifier of the electrical node where the Load/Energy source/BESS is connected
Load / Energy source / BESS id	Integer	Unique identifier of the Load/Energy source/BESS
Load / Energy source vector	String	Identifies the type of load (industrial, mobility, H2 production unit) or generating source (RES, conventional units)
Active Power Production / Consumption set-point	Floating point	Current production (kW/MW)
Timestamp	String	Identifies the timestamp in which the set-point should be established

Since the Energy Matching tool developments have not started yet, there is no data available that can be used to test the semantic model.

5.2.3 Smart and Green Logistics Tool

Objective

The Smart and Green Logistics tool being developed under MAGPIE 4.5.3 will essentially be a decisions support system (DSS) that will provide recommendations to the end-user of the tool on the choice of transportation mode(s) (i.e., a choice between rail, trucks, barge, or their combinations) as well as carrier(s) along with an estimate of charging requirements per mode. The objective of delivering such recommendations as the tool's output is to balance the cost and emissions generated over the entire 'container' transport chain from the Port to the destination in the hinterland. While the scope of the tool is currently limited to the operational level decisions that would be made 24-48 hours in advance, the tool can also be extended to inform and evaluate tactical and strategic level decisions in the future by simulating a range of 'What if?' scenarios.

The tool makes a few assumptions with respect to the scope: a) we only consider shipment of containers across the network and b) operations undertaken within the port (i.e., in-port) operations are not considered in detail. The tool developed within 4.5.3 uses (as input) the output of the GHG tool (developed in 4.5.1) i.e., the allocation of emissions to the different transport modes. This information provided by the GHG tool helps drive the decisions of selecting the greenest and cheapest transport chain from the port to the final container delivery destination. The output of the tool is fed back into the GHG tool for a detailed emission calculation. In a similar way, the tool uses inputs from 4.5.2 regarding the availability of energy, while the results are used by 4.5.2 to perform the energy matching in detail.

Market parties/stakeholders

The parties that are involved in the DSS are:

- Port Authorities, e.g., Port of Rotterdam and fellow ports
- Shippers
- Fleet Owners
- Terminal Operators

Connection to Digital Twin (I/O)

Table 10 lists the data the smart and green logistics tool will require from the DT - demand for shipment, the capacity for shipment and the state of the electricity grid.

Table 10 - Data needs smart and green logistics tool

Feature	Data Type	Description
Demand related data		
Container earliest arrival time	Timestamp	The earliest time at which the container would be available to be loaded and shipped at the port

Container latest departure time	Timestamp	The latest time by which the container should reach its final delivery destination
Container's arrival point	String	The location of the container upon arrival/ storage within port from where it needs to be loaded.
Container delivery destination	string	Address of the destination where the container needs to be delivered
Container weight	Floating Point	Weight of the container to be shipped
Shipment requirements	String	Any additional requirements that the shipment of the container needs to satisfy
Fleet related data		
Truck id	Integer	Identity number of the truck.
Truck propulsion type	String	Electric, H2 or fuel propulsion-based truck
Truck range	Floating point	Maximum distance travelled by a truck on a single charge
Speed (truck, barge, rail)	Floating point	Speed of the truck, Rail or barge carrying the container
Barge ID	Integer	Identify number of the barge
Barge Propulsion type	String	Electric or fuel propulsion-based barge
Barge range	Floating point	Maximum distance travelled by a barge on a single charge
Truck battery charging duration	Timestamp	Amount of time taken for the truck to charge its battery to its full capacity at a charging station
Barge battery charging service duration	Timestamp	Amount of time taken for a barge to charge/ swap its battery to its full capacity at a charging station
Rail ID	Integer	Identify the number of the train.
Carrier name	String	Name of the company owning the truck.
Carrier country	Integer	ISO code of the country of residence of the company owning the truck.
Truck Battery capacity	Integer	Capacity of truck battery (kWh).
Barge Battery capacity	Integer	Capacity of barge battery (kWh).
Truck Battery level (SoC)	Floating point	Percentage of energy left in the battery.
Barge Battery level (SoC)	Floating point	Percentage of energy left in the battery.
Reliability per mode	Floating point	Percentage of containers delivered on time based on historical data

Level of emissions (truck, rail, barge)	Floating point	The amount of emissions generated per km per mode. Comes from GHG tool.
Fleet size and capacity (truck, rail, barge)	Integer	Number and Capacity available of trucks, barges and rail
Rail network	Coordinates + connections	A description of the rail network that can be used by the trains, includes stations and connections between stations.
Rail timetable	Timestamp+ integer	Schedule of each rail ID arriving and departing from different terminals in the network
Barge network	Coordinates + connections	A description of the waterway network that can be used by the barges.
Barge timetable	Timestamp + integer	Schedule of each barge ID arriving and departing from different terminals in the network
Energy Related Data		
Predicted energy prices per time of day	Floating point	Expected energy price per time of day for the next day. Can be used as proxy for soft constraints on capacity of the grid
Predicted energy availability per time of day and location	Floating point	Expected energy capacity per time of day for the next day. Can be used as proxy for hard constraints on capacity of the grid
Charging station location	String	Location of the charging stations in the hinterland network
Charging station capacity	Integer	Number of free charging spots in the station
Charging power per charger	Integer	Capacity (power) of chargers at different locations.

A successful link between the Smart and Green Logistics tool and the Digital Twin lies on an effective answer to the following questions:

- What is the current energy level of truck x?
- What is the current energy level of barge x?
- What is the nearest energy station for truck x?
- What is the nearest energy station location for barge x?
- How many charging slots are left at Truck energy station x?
- How many charging slots are left at Barge energy station x?
- How much energy is left at Truck energy station x?
- How much energy is left at Barge energy station x?
- How many kilometers can truck x be expected to drive before it needs to recharge?
- How many kilometers can barge x be expected to traverse before it needs to recharge?

- What is the earliest pickup time of container x at port y?
- What is the latest delivery time of container x at final destination y?
- What is the final destination point of container x?
- What is the expected time of arrival of truck x at port y?
- What is the expected time of arrival of barge x at port y?
- What is the expected time of arrival of rail x at port y?
- What is the expected time of arrival of truck x at final destination y?
- What is the expected time of arrival of barge x at destination port y?
- What is the expected time of arrival of rail x at destination rail terminal y?
- What is the number of trucks available at port x to deliver container y?
- What is the average speed of the truck x delivering container y?
- What is the average speed of the barge x delivering container y?
- What is the average speed of the rail x delivering container y?
- What is the nearest rail terminal location to destination of container x?
- What is the nearest barge terminal location to destination of container x?

Data Flow

The tool will provide synchromodal transportation solutions which will allow switching between different transportation modes based on performance factors such as the carbon emissions, the utilization of the available resources and constraints such as service levels. Therefore, many actors will be providing data to the tool. However, the main flow be from shippers and truck/train/barge/ship owners and operators to themselves as the tool is expected to be a control tower at the operational level for the logistics chain. The DSS will provide modal shift recommendations during the flow of products in to and out of the port.

5.3 Use Cases at the demo level

The demo level use cases are currently under development. The preliminary version of the use cases is expected by M20, and the final versions by M30 with the delivery of the first version of the DT and digital tools in M30.

The description of the UCs is progressing in two stages. In the first demos 6, 9 and 10 – which have a wider context - are being fully characterized according to the script in Annex 2. The goal is to collect information on: scope and objective of the demo activities, the data needs (inputs and outputs), actors involved, data flows, general description of the underlying (logistics) processes and the expected links to the DT and digital tools. Generally, the leader of tasks T4.2 and T4.3 (TNO), and partners supporting these tasks (e.g., INESC, IFPEN, CEA, EDP) are working with the demo leaders to fully characterize the associated use cases. In parallel, the information provided by the UCs is being used for the development of the first version of the DT architecture, identification of additional digital tools' requirements and the conceptual data model (ontology).

In a second stage, the UCs of demos 2, 3 and possibly 7 will also be developed, building already on the description of demos 6, 9 and 10, following a similar process to the one described above.

6 Conclusions

This deliverable reported on the characterisation of participant ports, aiming to provide subsequent tasks, in particular tasks T4.2 and T4.3, with a better understanding about the operational context and organisational aspects of each port, its actors and their responsibilities within port ecosystems. Given the orientation towards fostering decarbonisation and optimising operations and energy consumption, a survey of existing and future digital platforms and related projects was carried out for each participant port. In accordance with an Enterprise Architecture approach, a mapping between port assets and digital platforms was established to identify digitalisation gaps that relate to the double transition effect and hinder the implementation of more sustainable, optimal operations within and outside ports. The characterisation also considers the typology of ports proposed in T9.1 of WP9, which encompasses dimensions such as governance, energy production and activities, and hinterland transport.

Some of the surveyed projects and digital platforms already allow for some interaction between port actors on regards to information exchange for optimising operations. Still, such platforms currently work as a data hub, in which most data are still provided through human input. Furthermore, real-time data about emissions levels and energy consumption are either unavailable, or not duly exploited. There is a latent opportunity for port authorities to exploit data to optimise operations, reduce emissions and energy consumption at the port level, and gain a better understanding about how ports may transit to more sustainable energy vectors.

The conceptual systems architecture of a Digital Twin for ports was herein proposed, to support several use cases related to the digital tools of this WP, and the demonstrators of MAGPIE. Such use cases were described in this report, with various levels of granularity according to their maturity level and work progress. In tasks T4.2 and T4.3, the use cases will be revisited and refined. A semantic model will form the foundation of the DT architecture, building upon the domain knowledge retrieved from the use cases and ongoing discussions with domain experts that relate to the actors of port ecosystems.

Further development of the DT and digital tools, as planned in WP4, will be made with the aim of producing tools that can be applied in other ports, beyond the MAGPIE ports. It is also expected that the use cases will continue to be refined in tasks T4.2, T4.3 and T4.4 to fully flesh out the data needs and ownership, the existing platforms that should be connected to the DT, the infrastructure that will give further support to the tools and DT and future access to the tools beyond the duration of the project and the MAGPIE consortium, and the ownership of the IP of the tools, where relevant. These details will be further refined in M30 with the delivery of the preliminary version of the DT and the digital tools.

Annex 1: Original task description

Task 4.1 Identification of Digital Platforms, data collection requirements, and services mapping (M1-M12) [APS, INESC, CEA, CIRCOÉ, IFPEN, TNO]

The goal of this task is to enhance the value-added by digital services and tools. This task will therefore carry out the extensive characterisation of the different digital platforms which support the port ecosystem. Based on an Enterprise Architecture approach the digital services needed to achieve the goals of the project (aligned with other WPs) are defined while framing the digital representation of the port ecosystem – Digital Twin. An assessment of the digital platforms and systems already existing or needed will be carried out – both at information systems and operational levels, as well as the characterisation of the data that should be exchanged with those digital platforms. To fulfil this goal, a detailed identification and characterisation of different platforms and data sources in the different domains of ports will be conducted that will be later exploited by T4.2 to T4.5. Through this, a framework to set up a digital ecosystem to enable the full exploitation of digital tools in subsequent tasks towards Green Ports' vision will be delivered, feeding WP9.

Annex 2: Use-case Requirements Form

Problem description

Please give a general description of the context and the problem the use case tackles. This should provide the eventual ontology engineer with the necessary context. Two paragraphs should on average be sufficient.

Example: In this use case we are experimenting with scheduling the charging of electrical trucks at the port. During its trip the truck signals its estimated time of arrival to the charging station together with its battery type. A charging station is recommended based on the availability of the truck and its type. A parking place should also be found for the truck after it has been fully charged.

Data sources

Please provide a list of data sources and/or APIs that in the next step are used for the demo. The data sources can both be data consumers (i.e., functions) or data producers (i.e., stores). Please also indicate for each data source its availability and the other features mentioned in the table.

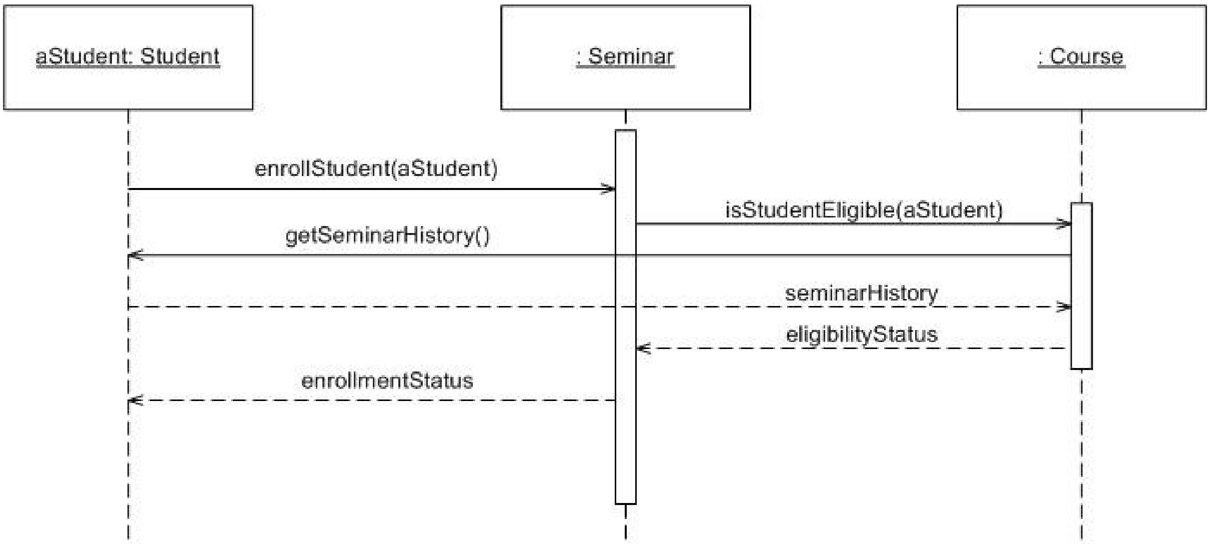
ID	Name	Schema available	API available	Example data	Live data	Security	Located at
DS01	Truck	Yes	No	JSON	No	No	
DS02	Charging station	No	No	CSV	No	No	
DS03	Charging station gate	Yes	Yes	JSON	Yes	Password protected	
DS04	Vehicle park	Yes	Yes	SPARQL	Yes	Password protected	

Legend

1. Identification: a simple code for unique identification of this data source.
2. Name: a human readable name
3. Schema available: is there a data schema available, such as XML schema or json schema?
4. API available: Do we have access to an API? This may both be real data as well as fictional data.
5. Example data: is there an example data set available?
6. Live data: do we have access to live data?
7. Security: is there some additional security that inhibits access?
8. Located at: where should we access the (example) data set or API?

Sequence diagram

Please provide an overview of how all the data sources should communicate with each other, for example as a sequence diagram. This diagram should generally include all data sources enumerated in the previous step.



Functional data requirements

The functional data requirements describe which questions the data sources should be able to answer. These are also called "competency questions". In the optimal situation, each functional data requirement should correspond to a competency question, which may optionally have additional nested CQs. The CQs together should cover all communication between the various data sources identified in the sequence diagram.

ID	Natural language	Example answer	Answer schema	CQ level (optional)
CQ1.1	What is the battery level of this truck?	99%	Percentage (i.e., 0 >= x <= 100)	Low
CQ2.1	What is the address of this charging station?	Streetname 123, City, Country	Address object	Low
CQ2.2	What are the other charging stations at this location?	ex:ChargingStation_1, ex:ChargingStation_2	List of Charging Station objects.	Medium
CQ2.3	What is the earliest available charging station for this truck type at this location?	20230202T00:00:00	xsd:dateTime	High

Legend

1. Identification: please provide a identification for each CQ. Useful standard way would be to have all follow: CQ<highLevelConcept>.<counter>. In this example we have used two high level concepts: trucks and charging stations.
2. Natural language: please provide the CQ as a normal natural language question, describing the question that one of the data sources should provide an answer to.
3. Example answer please provide a valid example answer
4. Answer schema: if available, please provide the schema or constraints that the answer should follow. For example, Boolean, string, integer between 0 and 100, or list of address objects.

5. (Optional) CQ level: if you're familiar with competency questions levels, please provide an indication whether the CQ is on the detailed atomic level, on the middle connectivity level, or on the high use case level.

Annex 3: Contribution to the Knowledge Portfolio

This is not applicable.