Swappable Container Waterborne Transport Battery

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Reducing the Cost of Large Batteries for Waterborne Transport

CD D8.3 – Route Infrastructure Study

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GLOSSARY OF TERMS

Term	Definition
CCNR	Central Commission for the Navigation of the Rhine
CD	Current Direct
Inland waterway vessel	A floating craft designed for the carriage of goods or public transport of passengers which navigates predominantly in navigable inland waterways or in waters within, or closely adjacent to sheltered waters or areas where port regulations apply
IWT	Inland Waterway Transport
IWW	Inland Waterways

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REVISION HISTORY

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0.2	10-01-2022	GK/RUT		First Version
0.3	07-02-2022	GK/RUT		Comments Revision
1.0	29/11-2024	GK/RUT		Final Revision

PROJECT SUMMARY

Current Direct, a new research and innovation project funded by the European Commission's Horizon 2020 program, will revolutionize the way we move goods and people by water. The vast majority of water transport in Europe is propelled by dirty, noisy diesel engines. By cutting the cost of today's marine battery electric drivetrains in half and relieving ship owners of the burden of capital expense, Current Direct will enable rapid adoption to reduce greenhouse emissions by 482.000 MT of CO2 equivalents per year.

Current Direct's innovative Energy as a Service platform will enable ship owners to accelerate their participation in the shift to clean energy while creating new business opportunities for shipyards and local entrepreneurs. By changing the model for acquiring and storing energy aboard vessels, Current Direct will create a new energy economy, adding thousands of new jobs. Current Direct provides a vehicle for energy companies, institutional investors, and government stakeholders to participate in the green transformation of Europe's merchant and passenger fleet.

Current Direct brings together twelve dynamic partners from across Europe's marine electrification value chain. The project is driven by Leclanché, one of the world's leading, fully vertically integrated battery energy storage solution providers and will be leveraging the expertise in state of the art active materials of Umicore. The University of Hasselt will use its electrochemical expertise to develop physics-based models of the Current Direct cells that will help optimize the life and return on investment of battery systems deployed across Europe as part of the Current Direct Energy as a Service platform developed by the accomplished engineers and data scientists at Rhoé Urban Technologies and Aviloo. Naval architecture and marine engineering company Foreship will lend its expertise to EDP CNET's in depth knowledge of electrical markets to ensure the Current Direct platform targets optimal vessels and locations maximizing reductions in emissions. VUB's material science experts are creating low-cost composites to improve the safety of battery packs that are designed for recyclability and feature VITO's smart cell monitoring electronics. Wärtsilä will develop modular battery containers and charging infrastructure that will be certified to innovative standards developed together with Lloyd's Register. The project will culminate in a demonstration of the Current Direct battery, shore charging, and asset management platform by Kotug in Amsterdam.

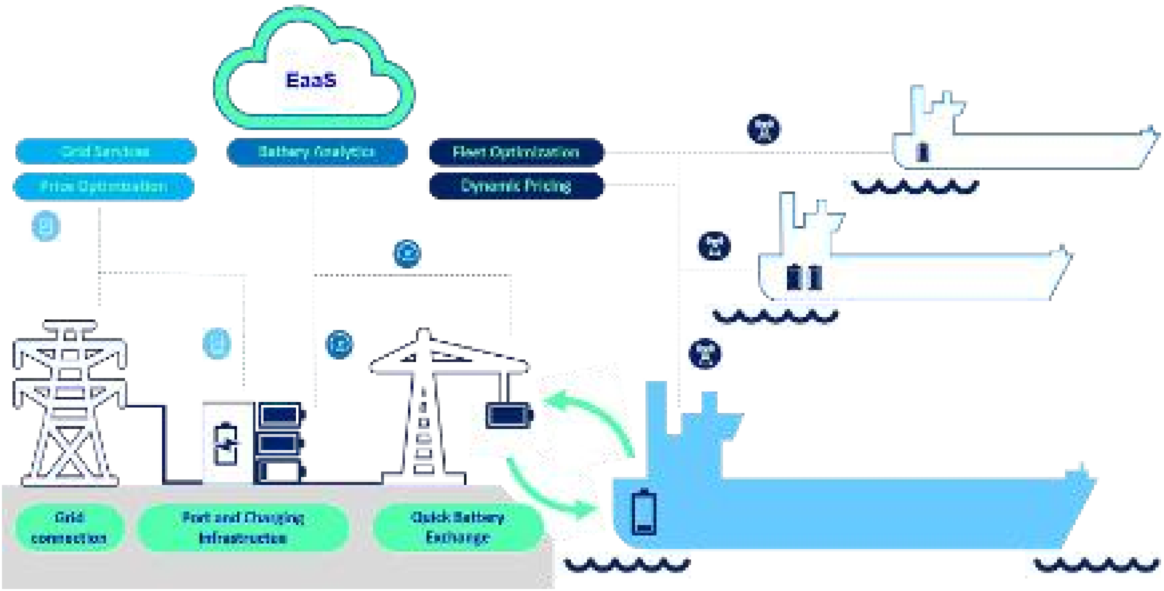

Figure 1: Depiction of Current Direct Project.

TASK APROACH AND METHODOLOGY

The task approach and methodology used is explained below.

During the kick-off meeting, the task objective and approach were agreed upon. It was agreed that the scope of this study was to identify the most suitable locations to roll-out a vessel charging infrastructure across selected EU inland waterways. It was also clear at that stage that the final reports of the sub-studies had a delay. Because of that, also this Location study was forced to adjust its timetable accordingly. Based on the adjusted scope, the next task phases were agreed upon with the Work Package 8 Partners.

Phase 1: The first phase of the study concerned of the Assessment of existing Route Infrastructure. The main Ports on important IWT Networks (Rhine, Danube etc) and ports with highest throughput were found during this phase. Furthermore, the IWT traffic in Rhine and Danube Basin was highlighted.

Phase 2: The second phase includes the Assessment of future Route Infrastructure. In this phase, the increased network connections, network capacity as well as hub investments and spoke-wheel architectures were presented.

Phase 3: The next phase was the Assessment of Available Infrastructure Requirements. The objective of this phase was to present the already available infrastructure along with the existing electric grid infrastructure.

Phase 4: This phase examined the Assessment of Current Direct Infrastructure Requirements. The scope of this phase was to identify the number, the size and the location of stations needed to be built. Moreover, this phase includes the assessment of the number of charging points each station requires. Furthermore, an estimation was made about how many batteries the network should have. Additionally, the already available equipment was highlighted and a future projection and forecast was made in order to support the full exploitation and commercialisation of the Current Direct solution.

Phase 5: The final phase includes the final report of the deliverable of the task 8.4 the Infrastructure Deployment Report.

2. PHASE 1 – ASSESSMENT OF EXISTING ROUTE INFRASTRUCTURE

2.1. Main Ports and Terminals on major IWT Network and their transports

Based on the Central Commission for the Navigation of the Rhine (CCNR) annual report of 2020-2021, the Main European Seaports are shown in Figure (2) (Dimensions of the circles depends on the million tonnes of loaded or unloaded cargoes.):

Figure 2: Main European Seaports. /CCNR Market Observation – Annual report 2021.

2.1.1 Rotterdam

Rotterdam, the largest European seaport, remains the market leader in the Hamburg-Le Havre range by total maritime cargo throughput as it holds 36.6% of market shares, followed by Antwerp (19.4%), Hamburg (10.6%) and Amsterdam (8%). The volumes of loaded or unloaded IWT cargo at the port of Rotterdam decreased by 2% to 149.7 million tonnes in 2020 (compared to 152.8 million tonnes in 2019 as seen in Figure (3)). The liquid cargo segment increased by 15%, while the dry cargo segment decreased by 14%. Container transport decreased by 5%. As observed in previous years, outgoing traffic continues to play an important role at the port (almost 70%). In 2020, 92,552 inland vessels visited the port of Rotterdam. Previously, 85,969 inland vessels visited the port in 2019 compared to 123,859 in 2018, 105,000 inland vessels in 2017 and 100,000 in 2016.

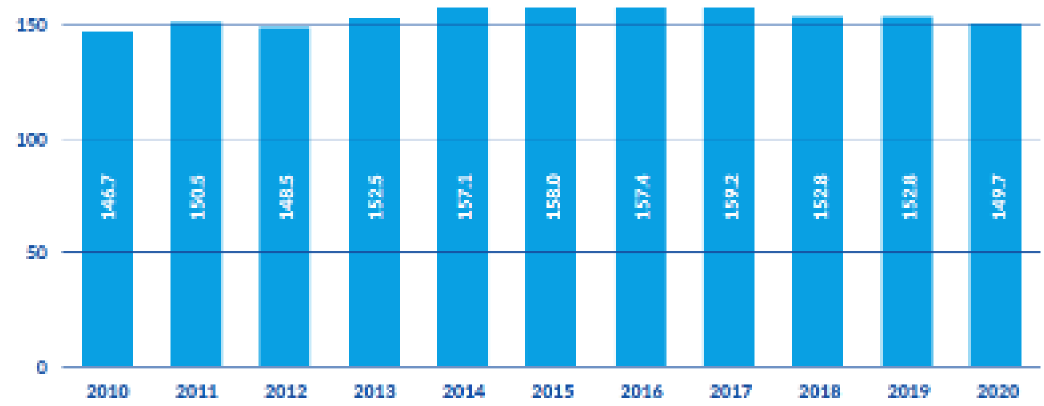

Figure 3: IWT in the Seaport of Rotterdam (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

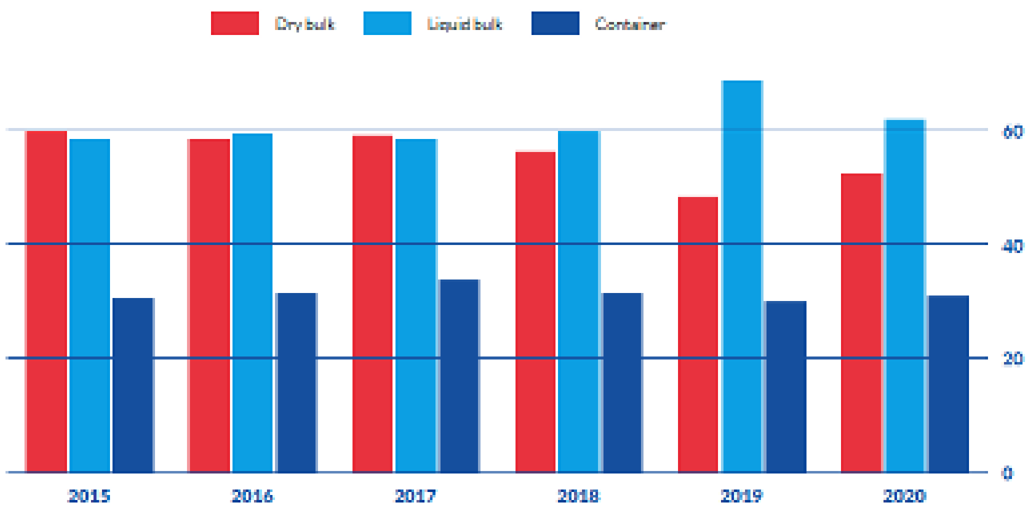

Figure 4: IWT in the Seaport of Rotterdam per Cargo Segment (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

2.1.2 Antwerp

In 2020, 56,583 inland vessels frequented the port of **Antwerp** compared to 56,585 in 2019, 59,724 in 2018, 59,268 vessels in 2017 and 58,006 in 2016. The IWT goods traffic at the port of Antwerp remained stable in 2020, reaching a volume of 101 million tonnes (compared to 101.3 in 2019 as seen in Figure (5)). The share of imports increased slightly while exports decreased marginally. Overall, compared to 2010, an increase of 15% in total IWT traffic at the port can be observed.

The modal split for total maritime throughput (but excluding industrial traffic) in 2020 was as follows: 45% road, 47.3% IWT and 7.7% rail (compared to the following figures in 2019: 47% road, 44.7% barge and 8.4% rail).

As in 2019, the main IWT market segments at the port in 2020 were petroleum products, chemicals and containers. The first two make up for more than half of the total river traffic at the port. Containers come close behind with a share of 25% of total river traffic.

Despite the Covid pandemic, imports of petroleum products increased by 28.5% in 2020 compared to 2019, while imports of metal products (-22.4%), fertilizers (-5.7%), chemicals (-4.1%) as well as crude minerals and building materials (-12.5%) decreased. On the export side, the situation was different, with the crude minerals and building materials segment recording a strong increase (+55.4%) and petroleum products sustaining a limited decrease. However, export of metal products has also strongly decreased (-29.9%).

The overall positive results for petroleum products can be explained by the few exceptionally good months for the transport of such goods to and from the port (March, November and December 2020). The main driver for such positive results was the decrease in oil prices.

Overall, solid fuels have been following a downward trend since 2010, driven by the energy transition. While reaching a high peak in 2017, volumes of metal products have decreased since then and sustained the most important loss in 2020 (-29%) of all other cargo segments. This negative result can be explained on the one hand by trade limitations (import quotas in particular) which, since Q3 2019, have led to strong declines in maritime volumes. The Covid crisis came as an additional factor which further affected demand, particularly in the automobile industry, thereby leading to a major decline in transport for this cargo segment.With regard to building materials, volumes have increased since 2015. For this segment, 2020 was quite particular since it recorded exceptionally good results (February 2020) but also extremely low ones (December 2020). Overall, the first half year 2020 was rather positive, while the second part of the year remained stable compared to the other years.

Container volumes remained stable in 2020 compared to 2019 but in general have been following an upward trend.

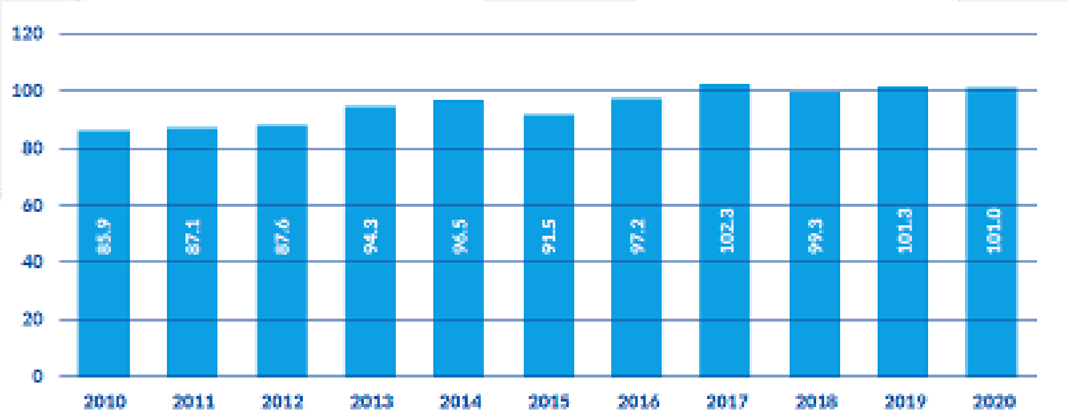

Figure 5: IWT in the Seaport of Antwerp (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

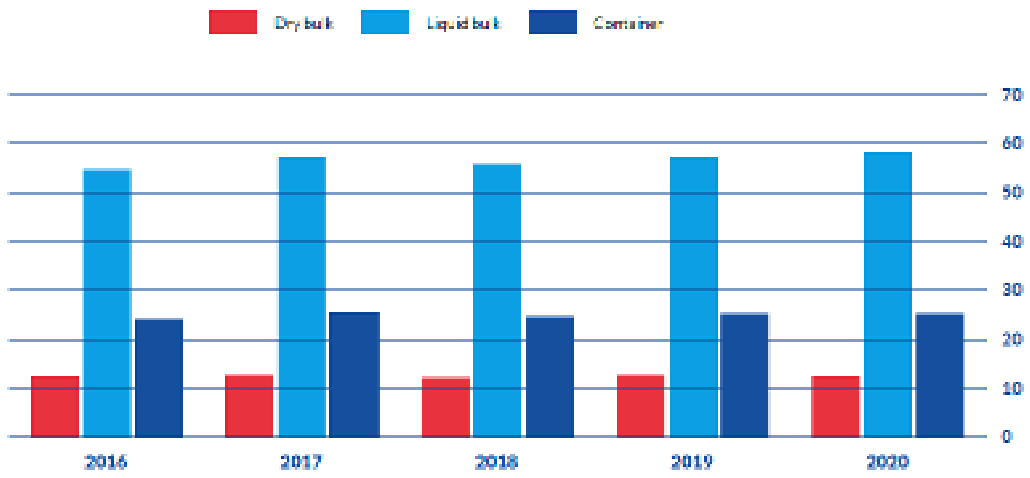

Figure 6: IWT in the Seaport of Antwerp per Cargo Segment (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

2.1.3 North Sea Port

In the **North Sea Port (Ghent, Terneuzen, Borsele, Flushing)**, total river traffic amounted to 54.95 million tonnes in 2020, a 6.1% decrease compared to 2019, mostly due to the Covid pandemic. In 2020, 41,446 inland vessels called at the port (compared to 47,000 in 2019). While in normal circumstances the evolution of seagoing and inland traffic is the same, it can be observed that inland waterway traffic was hit to a lesser extent than seagoing traffic (-11% compared to 2019), the latter also having to cope with the impact of Brexit.

Regarding inland waterway traffic at the port, dry bulk registered a small decline (-0.5%), mostly related to reduced volumes of minerals and building materials at the beginning of the Covid crisis, as a result of the first lockdown which lasted from March until May 2020. During this period, the construction industry was indeed at a standstill. On the liquid bulk side, the decline was stronger (-8.4%) mainly due to a decrease in liquid petroleum products. This is an indirect effect of the Covid crisis, which impacted transport movements and thereby use of liquid petroleum products. Transport of containers increased by 4.3%. It is worth noting that a decline of 39% was also observed for conventional goods. This was mostly due to a decrease in products from the metallurgical sector. The steel industry was indeed hit quite strongly by the crisis. In 2019, over 47,000 inland vessels entered North Sea Port to load and unload (around 40,000 in 2018)

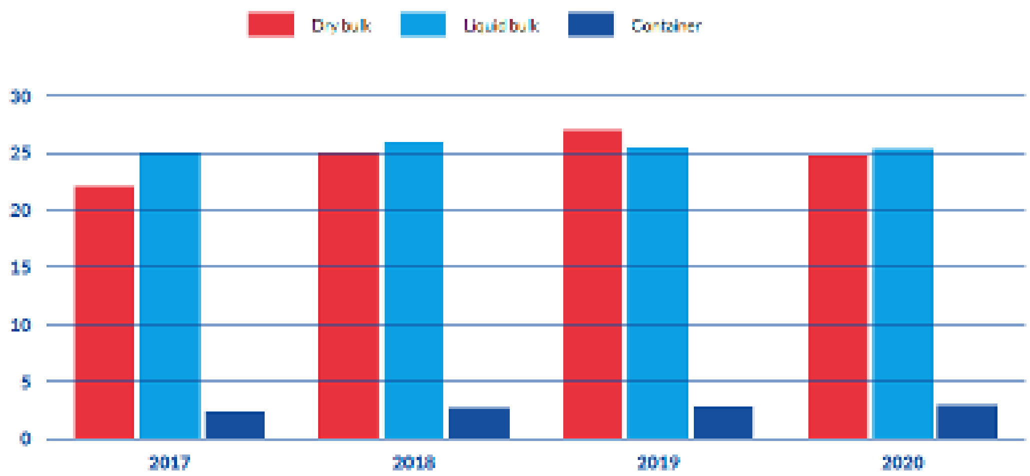

Figure 7: IWT in the North Sea Port (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

2.1.4 Hamburg

Volumes transported by IWT decreased by 6.1% in 2020 (8.3 million tonnes) compared to 2019 (8.9 million tonnes as demonstrated in Figure (8)) in the port of **Hamburg**. This result is mainly driven by the strong decrease in export volumes (-23.5%), while the import volumes increased (+13.6%). Of course, this is mostly linked to the Covid pandemic.

Overall, liquid cargo suffered the most from the pandemic, with a 23.4% decrease in transport volumes compared to 2019, which can be explained by the reduced transport volumes for coke and petroleum products (-24.3%). This market segment was strongly affected in many regions in Europe.

Dry cargo traffic remained rather stable, but had already sustained negative results in 2019, in particular coal transport, as a result of the shift away from coal as a source of electricity generation in Germany. In 2020, the downward trend observed for coal transport continued (-63.1%). This decrease seems to have been compensated by an increase in building material transport volumes (+16.4%), as well as secondary raw materials and waste (+38.4%). Overall, both dry and liquid cargo have, however, been following a decreasing trend since 2015.

The situation is more positive for container transport. Container transport increased by 8.9% and has been following an increasing trend, at a slow pace, since 2015.

In 2020, hinterland traffic consisted of 92 million tonnes of transported goods. With a share of 50.7%, railway transport is ahead of truck transport with 40.3% and IWT with 9%. In 2017, 19,315 inland vessels were counted in the port of Hamburg, compared to 20,382 in 2016.

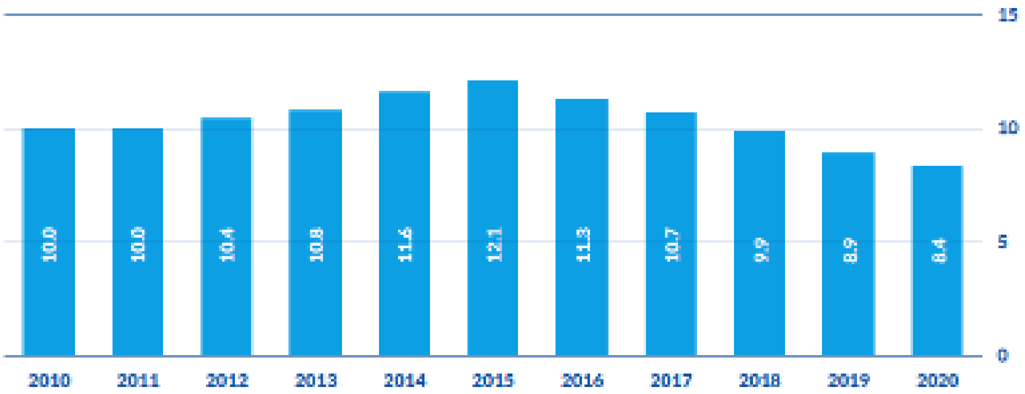

Figure 8: IWT in the Seaport of Hamburg (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

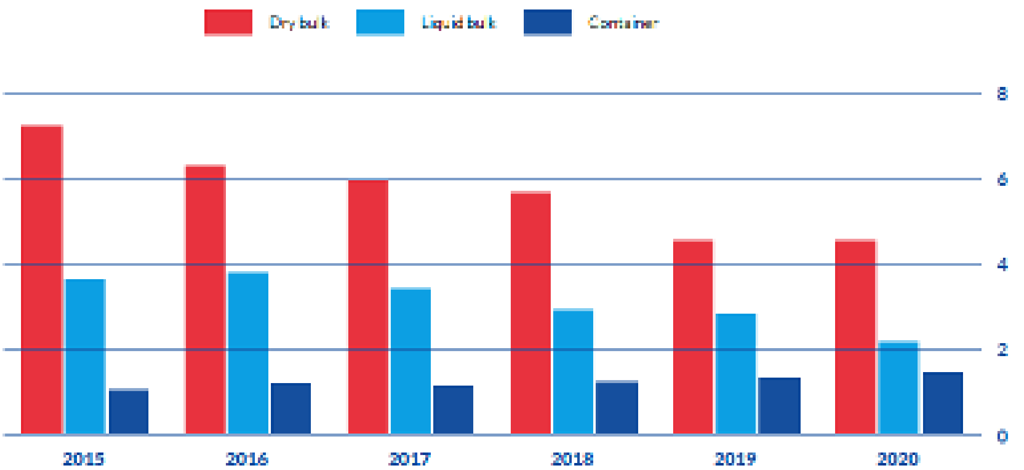

Figure 9: IWT in the Seaport of Hamburg per Cargo Segment (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

2.1.5 Constanţa

In **Constanţa**, 10,344 inland vessels called at the port in 2020 compared to 10,395 in 2019, 9,487 inland vessels called at the port in 2018. IWT decreased by almost 2%, to reach 14.9 million tonnes according to Figure (10). Mainly dry cargo is transported in the port of Constanţa, with a share above 90% of the total goods transported. Dry cargo volumes registered a slight increase compared to 2019 while liquid cargo registered a 27.3% decrease. Container, Ro/ro and general cargo amounted to 330 thousand tonnes in 2020, mostly attributed to general cargo. Indeed, container traffic in the port of Constanţa is low and has sustained a constant decrease since 2010.

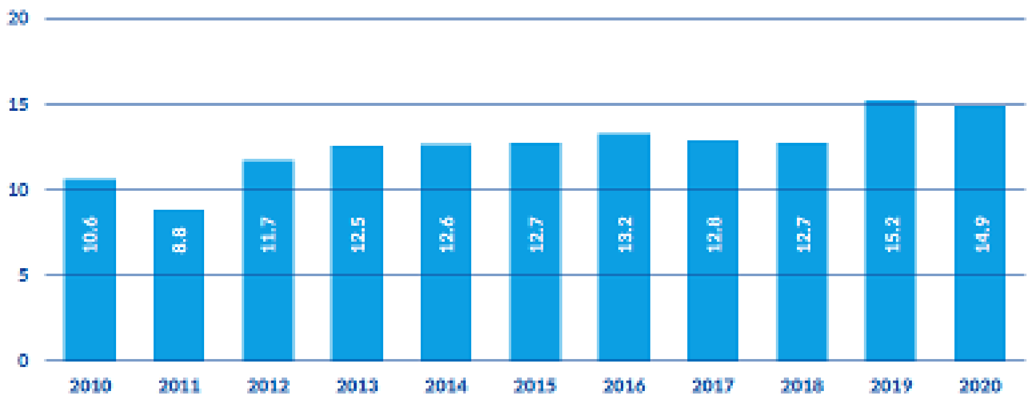

Figure 10: IWT in the Seaport of Constanţa (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

Inland waterway freight transport decreased in most seaports and inland ports in 2020. The development was less severe in seaports, as the results for Rotterdam (-2%), the North Sea Port (-6.1%), Hamburg (-6.1%) and Constanţa (-2%) show. The port of Antwerp held IWT volumes even constant.

Concerning the Main European Inland Ports, the CCNR annual report divides them into:

2.1.6 Rhine Ports

Figure (11) shows the IWT in Major Rhine ports from 2017 until 2020.

	2017	2018	2019	2020	2020/2019
Duisburg	52.2	48.1	47.8	42.4	-11.3%
Cologne	10.7	8.9	9.1	9.1	0%
Mannheim	9.7	7.5	7.9	6.9	-12.7%
Strasbourg	8.0	5.9	7.5	6.8	-9.5%
Neuss	8.0	7.6	6.9	6.5	-5.8%
Karlsruhe	7.2	6.4	6.9	6.2	-10.1%
Ludwigshafen	5.6	6.1	6.6	6.8	+3.0%
Basel	5.8	4.7	6.1	5.1	-16.4%
Mulhouse	4.8	4.4	4.9	4.2	-14.3%
Kehl	3.5	3.9	4.2	4.4	+4.8%
Mainz	2.9	3.2	3.7	3.6	-2.7%
Krefeld	3.4	3.3	3.6	3.0	-16.7%
Wesseling	2.6	2.0	2.7	2.5	-7.4%
Total	124.4	112.1	118.1	108.5	-8.0%

Figure 11: IWT in Major Rhine ports (In Million Tonnes) and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

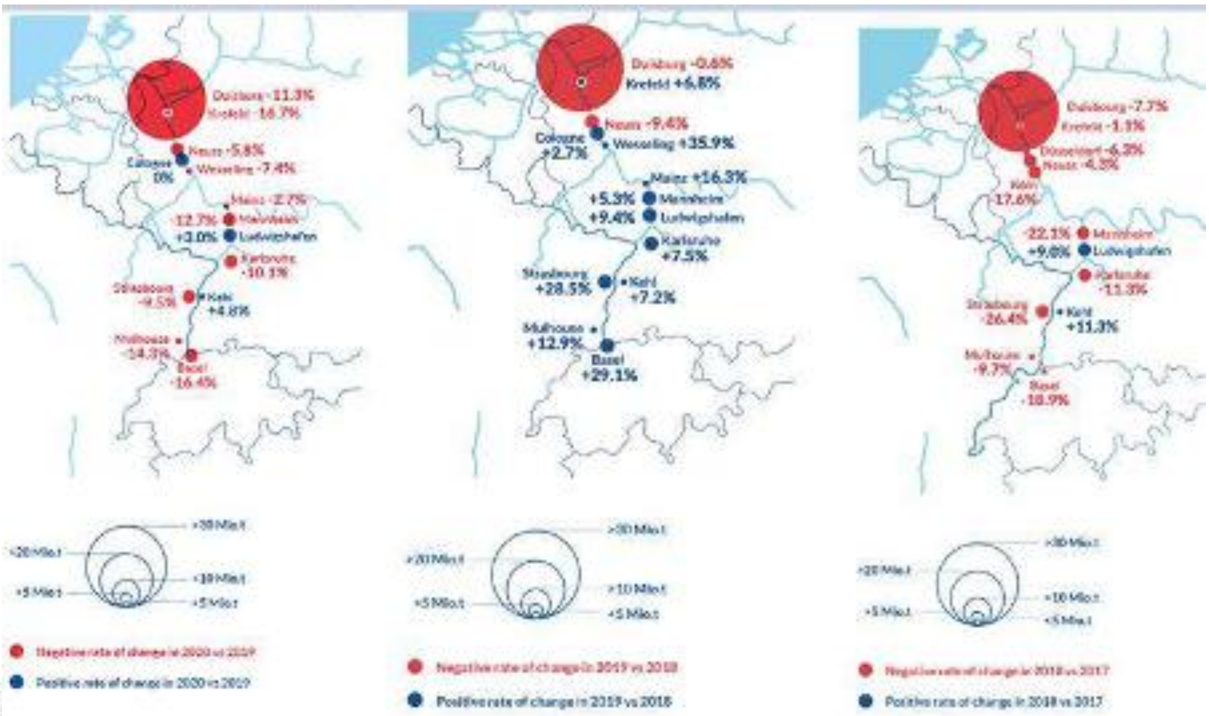

Figure 12: Total Yearly Waterside Traffic from 2017 until 2020 (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

Covid 19 affected the total yearly waterside traffic in negative rate of change in 2020 vs 2019 in contrast to 2019 vs 2018 where there was a lot of ports with positive rate of change as seen in Figure (12).

2.1.7 Duisburg

The port in **Duisburg** belongs to the most important inland river ports in Europe. The area of the port occupies 300 hectares. This port is equipped by 21 pools. In the case of transhipment activities, the port is focused on standardized containers, coal, liquid cargo and wheel technology. Transhipment capacity of the port enables accept 20 000 inland river vessels with carrying capacity up to 6000 tons.

The infrastructure of the port includes more than 200 km of rails. The port of Duisburg can reload cargo form 25 000 trains per year. Thanks to favourable connection to the public railway network, there are more than 400 regular train connections with more 100 destinations, not only in Germany but also abroad.

There are overall 8 container terminals in the port of Duisburg., equipped by 21 gantry cranes with container spreaders. These terminals can load and unload vessels with a capacity of 500 TEU. Every year, more than 4 million TEU is transferred through these container terminals.

Another important commodity, which is transported through the port of Duisburg, is coal. There are 5 terminals for transhipment of this type of cargo. The transhipment of liquid cargo is equally significant for the port of Duisburg. The port is equipped by 19 transhipment facilities for transhipment of liquid cargo. Storage capacity of tanks for liquid cargo is more than 0,6 million m3. Ro-Ro transhipment is also important for the port of Duisburg. There are 2 specialized berths for Ro-Ro.

There are also more than 130 transhipment facilities, which can load and unload cargo with weigh up to 500 tons. The storage capacity of the port of Duisburg is more than 2.2 million tons of cargo.

2.1.8 Cologne

German port in **Cologne** belongs to the most important inland river ports in Europe. More than 7000 inland river vessels are loaded and unloaded in this port every year. The carrying capacity of these vessels is over 3000 tonnes. So, thanks to this port, it is possible to reduce the number of trucks and heavy vehicles in Cologne and surrounding areas by more than 1 million.

The port on Cologne consists of seven parts - Godorf, Rheinauhafen, Deutz, Mulheimer Hafen, Niehl I a Niehl II. Godorf is located on the south near the city of Cologne. Liquid cargo, especially products of petrochemical industry, is transported through this part. Annual transhipment capacity of this part is more than 6 million tons of cargo.

In the past, the Deutz section focused on supplying the city with flour and wine. Today, there is a transhipment and storage of products and raw materials for the steel industry in this part. Waterfront gantry cranes operating in grab and hook mode are mainly used for transhipment. Approximately 100,000 tons of cargo are loaded and unloaded in this part annually for the needs of the steel industry.

Thanks to the transformation of the industry on the right bank of the Rhine, a new development project is planned in the Mulheimer area with the aim to transform this part into a residential and recreational area. In the past, this part served for the needs of the foundry. Today, it is used only for the needs of the shipyard and for parking vessels at its berths.

Parts Niehl I and Niehl II have the greatest importance for transhipment of cargo in Cologne. Part Niehl I has a universal character. There are transhipment sections for transhipment and storage of standardized ISO series containers equipped with a wide-gauge gantry crane for transhipment between vessel and railway wagon, or vessel and landfill. This section also provides options for transhipment and storage of general and liquid cargo.

Part Niehl II was focused on transhipment of petroleum products from the Esso refinery. In 1985, the refinery moved to the United Kingdom, and again, with the construction of solid ramps, it was successfully transformed into a transhipment of cars and vehicles. Thanks to these changes, almost 100,000 cars are currently reloaded in this section.

2.1.9 Karlsruhe

With a total cargo of around 7 million tonnes per year, the port of **Karlsruhe** is among the most significant inland ports in Europe. Since 1901, it has provided a link between the economic area of Karlsruhe and international Rhine shipping. It acts as a facilitator between the different freight forwarders and a link between industries and consumers. the port has thus created the essential conditions for the economic development of the city of Karlsruhe and the surrounding area.

The modern cargo facilities (including a container terminal and Ro-Ro facilities) and the unique flood barrage guarantee safety and optimum service.

2.1.10 Ludwigshafen

The port of **Ludwigshafen**, which has been operated since 1960 by the port company Ludwigshafen am Rhein GmbH, is the fifth largest public inland port in Germany and the largest in the Rhineland-Palatinate region with a ship handling volume of 7 to 8 million tonnes per year. Thanks to the close road and rail connections with the Rhine waterway, the port provides a traffic hub for the Rhine-Neckar region.

It covers an area of 120 ha and serves as a handling area for the raw materials and finished products processed in the region which are shipped all over the world from the port.

The port's function as a hub at the confluence of the Rhine and the Neckar and its excellent links with the nationwide road and rail network make this into a preferred location not only for numerous logistics service providers but also for industry with its worldwide outlet markets.

The main products concerned in addition to chemical products and fertilisers include mineral oil and mineral oil products, stone, soil and cement.

2.1.11 Strasbourg

The Port of **Strasbourg** is the second largest inland port in France. With links to the great sea ports of Rotterdam, Antwerp, Le Havre and Marseille via the Rhine and the railway network, and thanks to its high performance facilities, it constitutes a multimodal transport hub. Three hundred and fifty companies that provide 10,000 jobs in the region are based on the 1,360 hectares that the port installations cover (mainly in Strasbourg, but also in Lauterbourg, Beinheim and Marckolsheim).

RHINE EUROPE TERMINALS operates two modern, efficient, trimodal terminals to handle your goods and traffics, with excellent barge and train connections to the main European sea ports. These terminals are located in the port zone of Strasbourg, one in the South, the other in the North:

Strasbourg South Terminal (containers, heavy lift)

Strasbourg North Terminal (containers)

Otherwise, RHINE EUROPE TERMINALS operates also two port sites located in the north of Alsace:

Port of Lauterbourg (heavy lift, bulk)

Port site of Dalhunden (bulk).

2.1.12 The Swiss Ports

The Swiss Rhine ports provide a gateway to the sea. Over 10 percent of all Swiss imports, which arrive here along the Rhine via the seaports of Rotterdam, Antwerp and Amsterdam, are handled in **Basel**, **Birsfelden** and **Muttenz**. Large grain silos, storage areas for petrol and other mineral oil products and high container stacks can all be found here. Around 100 port companies process a large proportion of Swiss international trade.

2.1.13 Dutch Ports

Figure (13) shows the IWT in Major Dutch ports from 2017 until 2020.

	2017	2018	2019	2020	2020/2019
Rotterdam	159.2	152.8	152.8	150.6	-1.4%
Amsterdam	58.4	60.1	60.0	53.1	-11.6%
Vlissingen	13.4	15.3	19.9	17.0	-14.8%
Terneuzen	14.1	14.1	14.4	14.3	-0.4%
Moerdijk	9.5	10.2	10.2	10.9	+7.1%
Sittard-Geleen	4.2	6.3	6.8	6.4	-6.4%
Velsen	4.8	4.6	6.4	6.6	+3.2%
Urk	3.7	5.1	6.0	2.5	-58.2%
Dordrecht	4.7	5.3	5.7	6.4	+13.1%
Delfzijl	5.6	6.4	5.2	4.2	-19.1%
Nijmegen	2.4	2.8	4.1	5.1	+24.8%
Hengelo (O)	4.5	3.6	4.0	3.8	-3.9%
Gennep	3.5	3.7	3.2	3.2	-1.5%
Stein	3.6	3.6	3.1	3.1	-1.1%
Sluis	3.4	3.3	2.8	3.0	+7.7%

Figure 13: IWT in Major Dutch ports (In Million Tonnes) and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

Figure (14) shows the total Yearly Waterside Traffic in the Dutch Region.

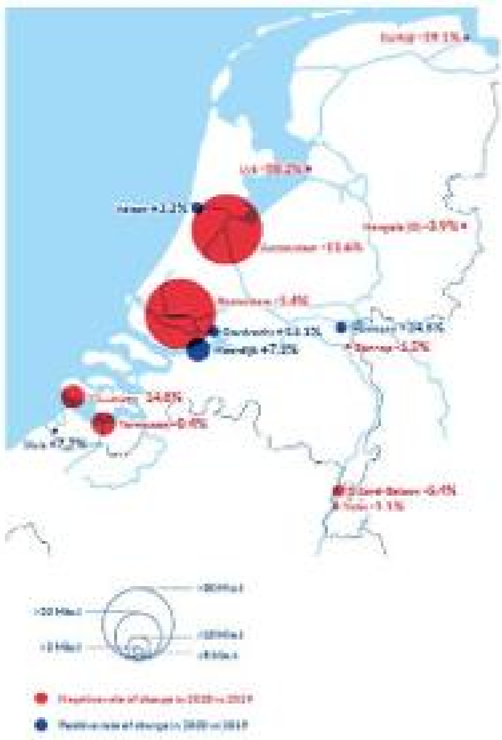

Figure 14: Total Yearly Waterside Traffic (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

2.1.14 French and Belgian Ports

Figure (15) shows the IWT in Major French and Belgian ports from 2017 until 2020.

	2018	2019	2020	2020/2019
Antwerp	99.3	101.3	101.0	0%
Paris	22.1	25.3	22.8	-9.7%
Liège	16.0	16.0	13.9	-12.0%
Strasbourg	5.9	7.5	6.8	-9.5%
Rouen	4.8	5.5	5.9	+6.0%
Brussels	5.2	5.2	4.9	-5.3%
Mulhouse	4.4	4.9	4.2	-14.3%
Namur	5.1	4.6	3.8	-16.3%
Le Havre	3.2	3.4	2.7	-19.6%
Marseille	2.5	2.8	2.0	-31.0%
Dunkirk	2.4	2.5	2.9	+16.0%
Metz	1.9	2.2	2.0	-7.2%
Lille	1.8	1.9	2.0	+8.0%
Lyon	1.4	1.1	1.0	-3.4%
Villefranche-sur-Saône	0.8	0.8	0.8	-7.0%
Chalon-sur-Saône and Mâcon	0.8	0.8	0.7	-10.7%
Thionville	0.6	0.7	0.6	-17.7%
Total	178.2	186.5	178.0	-4.5%

Figure 15: IWT in Major French and Belgian ports (In Million Tonnes) and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

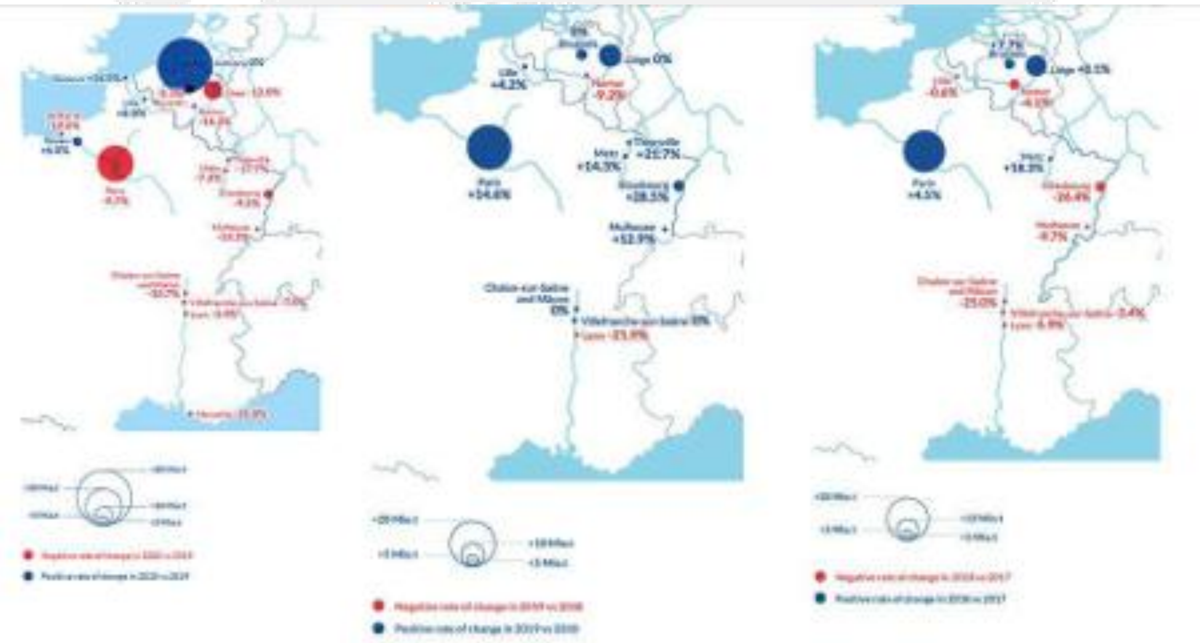

Figure 16: Total Yearly Waterside Traffic from 2017 until 2020 (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

Covid 19 affected the total yearly waterside traffic in negative rate of change in 2020 vs 2019 (except from the port of Antwerp) in contrast to 2019 vs 2018 where there was a lot of ports with positive rate of change as seen in Figure (16).

2.1.15 Danube Ports

Figure (17) shows the IWT in Major Danube ports from 2017 until 2020.

	2017	2018	2019	2020	2020/2019
Constanța	12.1	12.1	14.5	14.5	0%
Galati	6.3	6.4	5.9	4.5	-23.7%
Ismail	5.1	4.7	4.3	3.2	-24.0%
Smederovo	3.2	3.6	4.0	2.6	-35.0%
Linz	4.2	3.2	3.4	3.4	+4.0%
Bratislava	2.1	1.5	1.7	1.5	-11.7%
Tulcea	1.3	1.7	1.6	1.2	-26.9%
Pancevo	1.1	1.4	1.5	2.0	+35.0%
Novi Sad	1.2	1.0	1.4	1.6	+15.5%
Regensburg	1.5	1.1	1.3	1.5	+11.9%
Reni	1.1	1.3	1.3	0.8	-38.3%
Vienna	1.1	1.0	1.2	0.8	-17.3%
Drobeta Turnu Severin	1.2	1.1	1.2	1.0	-16.6%
Calarasi-Chiciu	0.7	0.7	1.1	0.9	-11.0%
Prahovo	0.9	1.0	1.1	1.2	+8.0%
Budapest-Csepel	1.1	0.9	1.1	1.2	+5.5%
Măcin-Turcoaia	0.8	0.8	0.9	1.2	+18.6%
Baja	0.6	0.3	0.5	0.8	+67.3%
Total	45.6	43.8	48.0	43.9	-8.5%

Figure 17: IWT in Major Danube ports (In Million Tonnes) and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

Figure 18: Total Yearly Waterside Traffic from 2018 until 2020 (In Million Tonnes). /CCNR Market Observation – Annual report 2021.

Figures (18),(19) shows the total Yearly Waterside Traffic in the Danube Region from 2017 until 2020.

Figure 19: Total Yearly Waterside Traffic for 2017-2018 (In Million Tonnes). /CCNR Market Observation – Annual report 2019.

2.2. IWT Traffic

In this chapter, inland waterways traffic that it's called any movement of a vessel on a given navigable inland waterway is presented.

Figure 20: Transport performance in main European river basins (In Billion TKM). /CCNR Market Observation – Annual report 2021

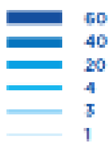

Figure (20), (21) shows the transport performance in main European river basins.

Figure 21: Transport performance in main European river basins (In Billion TKM). /CCNR Market Observation – Annual report 2021.

According to Figure (22), the types of inland waterways in Europe are presented below .

Figure 22: Types of inland waterways in Europe. /STC-NESTRA based on UNECE information.

As can be seen in Figures (23), (24) Rhine owns the larger percentage of transport. In the last years, Danube comes next overpassing the North-South Corridor and the other countries. In this research a subdivision of the European waterways is made into different sailing areas, namely the Rhine (and its tributaries), the Danube – as the main European waterways – and a selection of the most important and representative 'other waterways'.

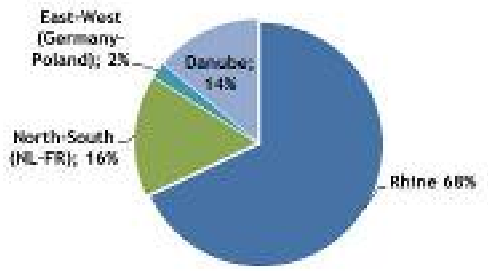

Figure 23: Transport performance in four main waterway corridors in Europe (in 2007). /NEA, et. Al. (2011). Medium- and long-term perspective of IWT for the EU.

Figure 24: Size of fleets (Number of inland vessels) per macro-region and vessel type in Europe. /CCNR Market Observation – Annual report 2021.

2.2.1 Rhine Basin

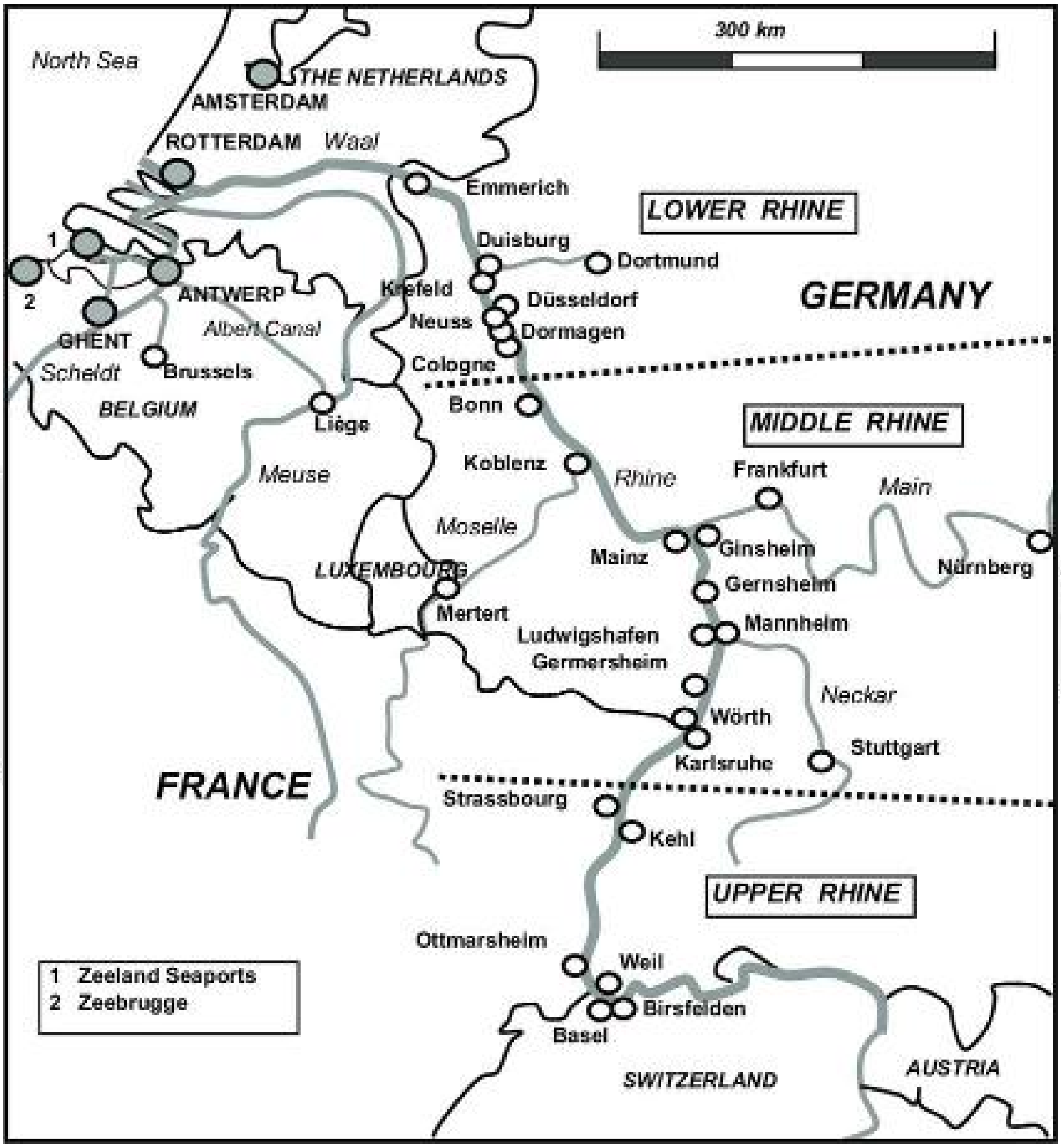

Figure 25: Map of the Rhine corridor/ T. Notteboom (2007)

Figure (25) shows the map of the Rhine corridor. Transport performance on the traditional Rhine decreased by 10% in 2020, compared to 15% in the low water year 2018, and 15% in the financial crisis year 2009. The only segment that registered higher figures in 2020 were agricultural products. Container transport nearly remained constant

Transport volume and transport performance on the traditional Rhine

Cargo transport on the traditional Rhine (from Basel to the German-Dutch border) amounted to 160 million tonnes in 2020, which represented a decrease of 8.4% compared to 2019. Transport performance on the traditional Rhine reached 32.6 billion TKM (as seen in Figure (26)), which was 10% less than in 2019. Total transport volume and transport performance on the traditional Rhine are calculated by the

German Statistical Office Destatis, based on information provided by ports and skippers. (RHINE TRANSPORT DATA (DESTATIS): the calculation is based on information provided by the skippers to the ports. On arrival in a port, the skipper informs the port, which forwards the information to the relevant regional statistical office, which in turn forwards it to the central headquarters of the German Statistical Office in Wiesbaden. As far as the distance travelled is concerned, the port of origin and the port of destination for all transported goods are taken into account. In order to be able to specify the distance covered, the skippers have the possibility of indicating marked points or landmarks that they have passed on their journey. If one or more such landmarks are specified, Destatis determines the shortest route that takes these marked points into account. If no landmarks are specified, the shortest route in terms of kilometres is assumed.)

The Rhine basin is the most developed, maintained and utilized for the transportation purposes part of the AGN network. It is characterized by the highest population and waterway density and its share of the upper classes of inland waterways is considerably higher than on other European inland waterways.

Infrastructure projects in the Rhine basin and East across northern Germany to Poland and the Baltic countries essentially aim to eliminate strategic bottlenecks and to increase the carrying capacity on routes converging on the Rhine. Construction on the Mittelland Canal route (E 70), for upgrading to class Vb, has been completed through to Berlin. It is now being followed-up with the Niederfinow enlargement by construction of a new barge lift. Work is ongoing on doubling of the locks on the Mosel and increasing its carrying capacity by deepening the channel for vessels drawing up to 3 m. The Rhine basin will soon acquire further density, improved operating conditions for carriers and new possibilities of supply, especially in container transport, by implementation of the Seine-Scheldt waterway project, including the 106 km long Seine-Nord Europe Canal (E 05, class Vb). The canal will provide a link from the Rhine basin to the currently isolated western part of E 80 and E 80–04.

A weakness of the existing main network interconnection with the new EU member States east of Germany is the poor overall condition of the inland waterways of Poland, i.e. route E 70 east of the Oder. Waterways of international importance (classes IV and Va) represent only 1.9 and 3.0 % respectively of the total length of 3,650 km of waterways in this country. The Polish Government identifies all the main routes (E 30, E 40 and E 70) as “basic bottlenecks” where upgrading from Class I, II or III to Class Vb is required, but at present none of these projects are on the agenda of the Polish Government. Poland can play an interconnecting role between the waterways of Western Europe and the waterways of the Russian Federation through the river Bug, but free-flow navigation poses serious problems of variable hydrological regimes and available depths. Moreover, environmental protection lobbies oppose major engineering works (whether free-flow or canalization). In this context, investment decisions are taken in some countries on the assumption that neighbouring countries will eventually make compatible infrastructure investments as per AGN, to provide a coherent overall network.

Less critical to the development of traffic is the E 70 “missing link” (Twente to the Mittelland Canal), which was included in the AGN, as a long-term project. Discussions in the Netherlands on this canal have led to the conclusion that the project could only be realized at very high costs and very little gain and that there exists sufficient alternative routes for inland navigation. The Netherlands, therefore, supports deletion of this project from the AGN missing links. This position is shared by Germany.

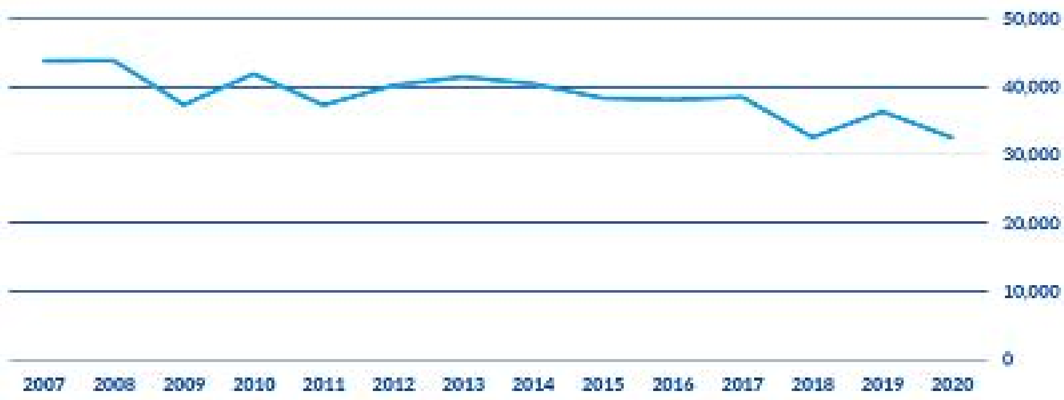

Figure 26: Transport performance on the traditional Rhine (In Million TKM). /CCNR Market Observation – Annual report 2021.

Rhine transport at specific measurement points

Along with the overall cargo transport on the traditional Rhine (160 million tonnes), cargo transport can also be measured at specific measurement points (locks or border points). The relevant volumes represent the transport activity only at these particular points in a geographical, snapshot type of approach.

The following table in Figure (27) contains a set of measurement points in the Rhine basin which is used by the waterway and shipping administration in Germany.

Rhine stretch / affluent	Measurement point	Name of measurement point	Volume of transport in 2020 in Mio. tonnes	Rate of change 2020/2019
Lower Rhine	Border Germany/ Netherlands	Emmerich	130.0	-7.9%
Upper Rhine	Border Germany/ France	Lock of Iffezheim	19.2	-9.9%
Main	Junction of Main and Rhine	Lock of Mainz-Kostheim	13.5	+2.3%
Moselle	Junction of Moselle and Rhine	Lock of Koblenz	8.1	-14.5%
Neckar	Junction of Neckar and Rhine	Lock of Mannheim-Feudenheim	5.1	-5.6%

Figure 27: Table of measurement points for freight transport in the Rhine basin and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

Locks on the Rhine

The purpose of this part was to locate the locks on the Rhine and Danube Basins in order to investigate the potential of placing Current Direct swappable stations. There are 10 locks on the Rhine as demonstrated in Figure (28), all built as part of important hydroelectric power schemes. The first four are on the Grand Canal d'Alsace, the remaining six on diversion canals. Each lock comprises two chambers side by side, one 185 by 24m, the other 185 by 12m. In view of the heavier traffic downstream of the busy port of Strasbourg (12 million tonnes per year), the two locks added in the 1970s and early 1980s, at Gambsheim and Iffezheim, each have two 270 by 24m chambers.

Figure 28: Locks on the Rhine. /Frenchwaterways.com.

2.2.2 Danube Basin

Despite of reductions in iron ore, metals and coal transport, transport performance on the Danube decreased by 1.4% only in 2020, thanks to a vital upsurge in transport of agricultural products.

Transport volume and transport performance on the Danube

Cargo transport on the entire navigable Danube between Kelheim (Germany) and the Black Sea in Romania lies in the range between 36 and 40 million tonnes per year.6 The transport performance on the Danube (EU Danube countries plus Serbia) reached 25.8 billion TKM in 2020, which was 1.4% less compared to 2019 (as seen in Figure (29)).

By contrast, the issues on the Danube relate to the intrinsic navigability and carrying capacity of the river itself and its tributaries and connecting waterways. Hence the strategic bottleneck of limited draughts in the Straubing-Vilshofen section of the Danube (currently guaranteeing no more than 1.55 m draught), and other sections offering less than the required 2.50 m in Romania/Bulgaria, Serbia and Hungary (for a variable number of days in the year, 7–15 in some cases, but up to 2 months or more). Eliminating these bottlenecks, to the extent possible, is the aim of the EU Priority Project 18 under the Trans-European Transport Network (TEN-T) programme. The project aims to establish uniform characteristics throughout the 3,000 km long waterway from the North Sea to the Black Sea. With the goal to maintain the fairway parameters on the entire course of the Danube, ensuring its economically beneficial exploitation by all participants of international navigation, it is necessary that all interested countries carry out the works on maintaining the river's navigational characteristics.

The contrast in network penetration between the Rhine and the Danube basins is also pronounced, considering the very poor conditions of navigability on all the tributaries of the Danube, none of which provide service as "feeders" of the artery in the way that the canalized Mosel, Main, Neckar, etc, effectively "feed" traffic to the Rhine.

Figure 29: Transport performance in freight transport on the Danube (In Million TKM). /CCNR Market Observation – Annual report 2021.

Danube transport at specific measurement points

The statistical system used for observing Danube cargo transport at certain measurement points is similar to the system in the Rhine basin. The waterway administrations register data at certain borders or measurement points which are described for the Danube in the table below (Figure (30)).

Danube stretch	Measurement point	Name of measurement point	Volume of transport in 2020 in Mio. tonnes	Transport volume 2020/2019
Upper Danube	Border Germany/ Austria	Lock of Jochenstein	2.3	-30.0%
Upper Danube	Border Slovakia/ Hungary	Lock of Gabčíkovo	5.0	-14.2%
Middle Danube	Border Hungary/ Croatia/Serbia	Mohács	6.1	+9.5%

Figure 30: Table of measurement points for Danube freight transport and rate of change 2020/2019. /CCNR Market Observation – Annual report 2021.

Locks on the Danube

There are a total of 18 river power plants on the Danube waterway (from Kelheim to Sulina), 16 locks on the Main-Danube Canal (30 minutes maximum time in lock. This time includes the principal operation of locks meaning that the vessel enters the lock, waits until the lock starts to fill or empty and then moves out of the lock) and 2 locks on the Danube-Black Sea Canal (as seen in Figures (31),(32)). These generate energy by utilising the gradient of the river and the accumulation of water behind the dam. Locks are used to enable vessels to overcome the resulting differences in height along the river and can consist of one or more (usually two) chambers. Fourteen of the eighteen locks on the Danube have two lock chambers, thus enabling the simultaneous locking of vessels travelling upstream and downstream.

Due to the steep gradient of the Upper Danube between Kelheim and Gönyu, there are a total of sixteen power plants with locks. On the Middle and Lower Danube there are only two locks. These are situated at the Iron Gates, a gorge forged by the Danube through the Carpathians, which forms the border between Romania and Serbia. These two locks are also the largest on the Danube: The locks Iron Gate I (river km 942.90) and Iron Gate II (river km 863.70/ 862.85) each have two lock chambers which are 310 metres long and 34 metres wide, located on the right bank and the left bank. The lock chambers on the right bank (Djerdap I and II) are maintained and run by Serbia, while those on the left bank (Portile de Fier I and II) are maintained and run by Romania.

Lock	Country	River-km	Lock chambers L x W (m) | No.
Abwinden-Asten	AT	2119.54	230 x 24 | 2
Altenworth	AT	1980.11	230 x 24 | 2
Aschach	AT	2162.67	230 x 24 | 2
Bad Abbach	DE	2397.17	190 x 12 | 1
Freudenau	AT	1921.05	275* x 24 | 2
Gabcikovo	SK	1819.15	275 x 34 | 2
Geisling	DE	2354.29	230 x 24 | 1
Greifenstein	AT	1949.20	230 x 24 | 2
Jochenstein	DE/AT	2203.33	230 x 24 | 2
Kachlet	DE	2230.60	230 x 24 | 2

Figure 31: Locks on the Danube. /Viadonau.org

Lock	Country	River-km	Lock chambers L x W (m) | No.
Melk	AT	2038.06	230 x 24 | 2
Ottensheim-Wilhering	AT	2146.82	230 x 24 | 2
Regensburg	DE	2379.68	190 x 12 | 1
Straubing	DE	2324.13	230 x 24 | 1
Wallsee Mitterkirchen	AT	2095.06	230 x 24 | 2
Ybbs-Persenbeug	AT	2060.42	230 x 24 | 2
Djerdap/Portile de Fier I	RS/RO	942.95	310*x 34 | 2
Djerdap/Portile de Fier II	RS/RO	863.70	310*x 34 | 2

Figure 32: Locks on the Danube. /Viadonau.org

3. PHASE 2 – ASSESSMENT OF FUTURE ROUTE INFRASTRUCTURE

3.1. Increased Network Connections

In 2018, the 335 ports of the Trans-European Transport Network (TEN-T) core and comprehensive networks14 handled 3.8 billion tonnes of cargo. Almost three quarters of this volume were handled in the 84-core network corridor (CNC) ports.

Figure 33: European Core Network Corridors and ro-ro shipping routes. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

Six major sea basins can be distinguished in Europe: the Baltic Sea, the North Sea, the Atlantic, the Western and the Eastern Mediterranean, and the Black Sea (as can be seen in Figure (33)). These sea basins are all characterised by a more intensive exchange within than between basins, though they are, of course, interconnected among each other. In addition, there are maritime ports in the EU's outermost regions (e.g. Azores, Madeira, the Canary Islands, Guadeloupe, Martinique, Reunion Island and French Guiana). Out of the total 3.8 billion tonnes handled in 2018, almost two thirds were related to short sea traffic. Short sea shipping (including feeder traffic) had a particularly high share in the Baltic Sea, the Eastern Mediterranean and the Black Sea.

The largest volume of cargo is handled in the North Sea basin. Its 20 CNC ports handle 1.4 billion tonnes per year, equal to more than one third of the total EU maritime traffic. It is followed by the Western Mediterranean (around 500 million tonnes) and the Baltic Sea (around 350 million tonnes). The Atlantic basin has the largest volume handled in core ports which are not part of the core network corridors. Taken together, all Atlantic core ports handled around 360 million tonnes.

	Total cargo volume handled (mln tonnes)				of which short sea	
sea basin	CNC ports	other core ports	comprehensive ports	Total	million tonnes	share of total
Baltic Sea	355	16	183	554	470	(85%)
North Sea	1.386	89	118	1.593	912	(57%)
of which UK	*167*	*89*	*58*	*314*	*232*	*(74%)*
Atlantic	213	154	109	477	287	(60%)
of which UK	61	44	41	146	106	(72%)
Western Mediterranean	522	45	144	712	477	(67%)
Eastern Mediterranean	249	0	55	305	225	(74%)
Black Sea	58	0	12	69	51	(74%)
Outermost regions	0	29	14	43	26	(61%)
Total EU maritime ports	3.011	466	735	4.213	2.786	(58%)
of which short sea	*1.734*	*216*	*500*	*2.449*		
	(58%)	*(46%)*	*(68%)*	*(58%)*		

Note: UK ports are no longer part of the TEN-T network after the UK left the EU. The presented figures are for 2018, hence still including the UK.
Source: ISL based on Eurostat, 2019

Figure 34: Maritime cargo traffic by major sea basins, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

The Eastern Mediterranean (around 250 million tonnes) and the Black Sea (around 60 million tonnes) are the regions with the smallest absolute volumes, but they have also been the fastest-growing basins with 3.4% and 3.1% average annual growth between 2010 and 2018, respectively. During the same period, the EU average was 1.9%.

There are several dozen regular short sea links between the different sea basins and hence between different parts of the European TEN-T Network. Broadly speaking, two types of short sea shipping services can be distinguished: those bridging straits or connecting islands (e.g. across the Fehmarn Belt, the Strait of Gibraltar or the English Channel) and long-distance services along coastal lines that form an alternative to parallel land-based routes. The former are sometimes part of a core network corridor (e.g. the connection between South Italy and Malta), while the latter connect different corridors (e.g. services in the Western Mediterranean between Italy and Spain) or run in parallel to such corridors (e.g. North Sea-Baltic or Atlantic coastal services).

Despite a relatively small number of direct deep-sea services, the Baltic Sea and the Black Sea strongly rely on short sea connections with the North Sea and the Mediterranean Sea, respectively. In the North, there is an extensive exchange between the North Sea and the Baltic Sea – more than between any other pair of basins in Europe. In early 2019, there were around 60 regular short sea container services and almost 40 regular ro-ro services between these two seas.15 In the South, the Black Sea is connected to the Mediterranean with around 20 short sea container services and five ro-ro services (excluding car carriers). The Atlantic Coast provides around 50 regular container and ro-ro connections with the outermost regions, particularly with the Azores, Madeira, the Canary Islands and the French Caribbean.

In order to fully develop the potential of Motorways of the Seas, the role of each basin and its maritime ports has to be acknowledged. The relevant traffic structures in each sea basin are highlighted below.

3.1.1 Baltic Sea

Four core network corridors connect the Baltic Sea with the European hinterland. Two corridors start in ports of the southern coast (Northeast Germany and North Poland) and move southwards (Orient-East Med and Baltic-Adriatic). The Baltic Sea ports connect them with Sweden and Denmark through a dense network of ro-ro services and with other Baltic Sea countries through ro-ro and container services, including the non-EU countries Norway and Russia.

Further to the West, the Scandinavian-Mediterranean Corridor connects to the ports of Lübeck and Rostock with the continental European hinterland. Unlike Orient-East Med and Baltic-Adriatic, the corridor continues to Denmark, Sweden and Finland. This part of the corridor is hence in parallel to several ferry routes between the German Baltic Sea ports on the one hand and Denmark, Sweden and Norway on the other hand. The current land route via Jutland and the Öresund between Copenhagen and Malmö is actually mostly used for direct block trains, while most of the cargo travels in trucks, trailers and rail waggons on one of the ferry routes. There is hence competition between the land and maritime routes, but also the possibility for forwarders to prepare synchromodal offers – especially after the opening of the Fehmarn Belt fixed link that will make land-based transport more attractive. For transport between Sweden and Finland, the Scandinavian-Mediterranean Corridor actually includes a short sea link (Stockholm-Turku).

The North Sea-Baltic Corridor stretches along the southern and eastern coast of the Baltic Sea, crossing Germany, Poland, Lithuania, Latvia, Estonia and Finland. Here again, there is a parallel maritime route from Belgian, Dutch and German CNC ports to the Baltic States and Finland. The maritime route takes more time but is considerably cheaper than the land-based route (mostly truck traffic due to the lack of regular rail services). The northernmost section of the corridor is the ro-ro link between Tallinn and Helsinki.

Besides the links on or in parallel to CNCs, there are various maritime links between CNCs, e.g. Swinoujscie (Baltic-Adriatic) and Trelleborg (Scandinavian-Mediterranean) or between Riga (North Sea-Baltic) and Stockholm (Scandinavian-Mediterranean) (as can be seen in Figure (35)). Due to their geographical location, maritime transport is particularly important for Lithuania, Latvia, Estonia and Finland for connecting with other EU markets.

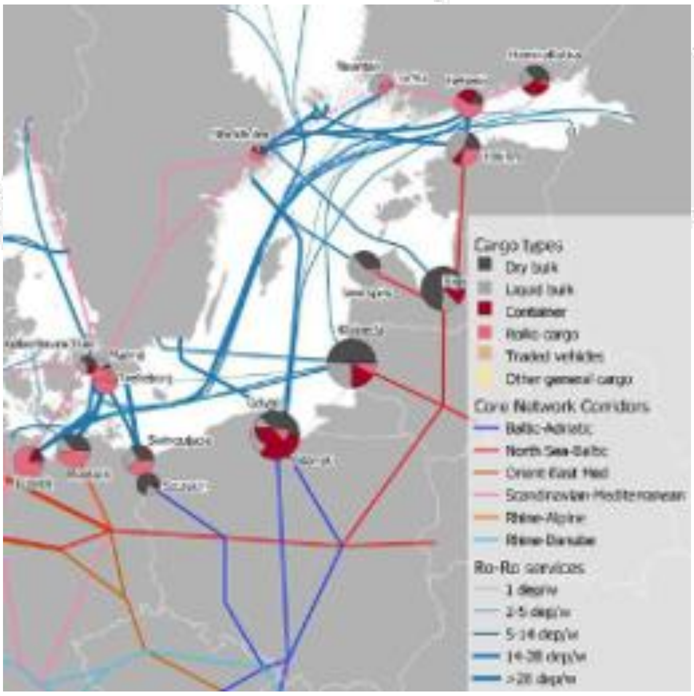

Figure 35: Core network Corridor ports and regular ro-ro services in the Baltic Sea basin, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

3.1.2 North Sea

With 1.4 billion tonnes handled in 2018, the North Sea18 core network corridor ports are by far the busiest group among the six sea basins. They represent more than half of the total CNC port traffic of the EU.

Six core network corridors connect the North Sea ports with their hinterland as demonstrated in Figure (36). Most of them – the North Sea-Mediterranean, the Rhine-Alpine, the Scandinavian-Mediterranean and the Orient-East Med Corridors – are North-South corridors and hence important hinterland connections of the North Sea ports. The Scandinavian-Mediterranean Corridor marks the eastern end of the North Sea and is the only one connecting Sweden (and also Norway) with the main continent. There are parallel maritime connections, but mostly from Baltic Sea ports. The North Sea-Mediterranean Corridor marks the western end and connects Great Britain and Ireland with the continent. It includes Europe's busiest ro-ro route, namely Dover-Calais, and also Dover-Dunkerque.

While it is not clear yet how Brexit will change traffic flows on these links after the transitional period, it is already clear that the busiest ro-ro routes in the area will become connections with a neighbouring country rather than links on an intra-EU Core Network Corridor. An intensification of direct links between the continent and Ireland could shift away volumes from the cross-channel links.

The two other corridors – namely the Atlantic Corridor and the North Sea-Baltic Corridor – include important hinterland axes for Le Havre, Rouen, the Benelux ports and the German north range ports.

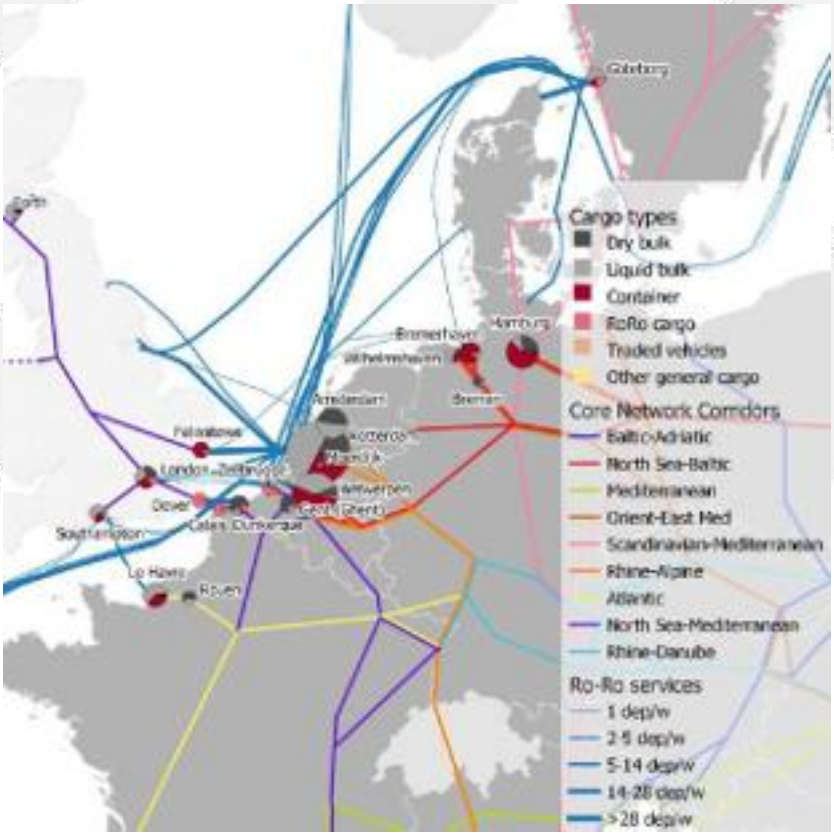

Figure 36: Core Network Corridor ports and regular ro-ro services in the North Sea basin, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

3.1.3 Atlantic Sea

The European Atlantic Basin includes Ireland, Portugal and the western coasts of Great Britain, France and Spain (as seen in Figure (37)). The most important core network corridors connecting the basin's ports with the hinterland are the Atlantic and the North Sea-Mediterranean Corridors. The former connects the Portuguese ports Lisbon, Leixoes and Sines via Bilbao and Bordeaux with the Paris area and Southwest Germany. The corridor also includes Le Havre and Rouen as the two North Sea ports and Algeciras in the strait of Gibraltar. It will include from 2021 on the port of Nantes Saint-Nazaire, too. While there are no direct ro- ro services between these ports, there are several services in parallel to the corridor, for example connecting Leixoes with Rotterdam, Nantes Saint-Nazaire with Vigo or Bilbao with a ro-ro service to Belgium.

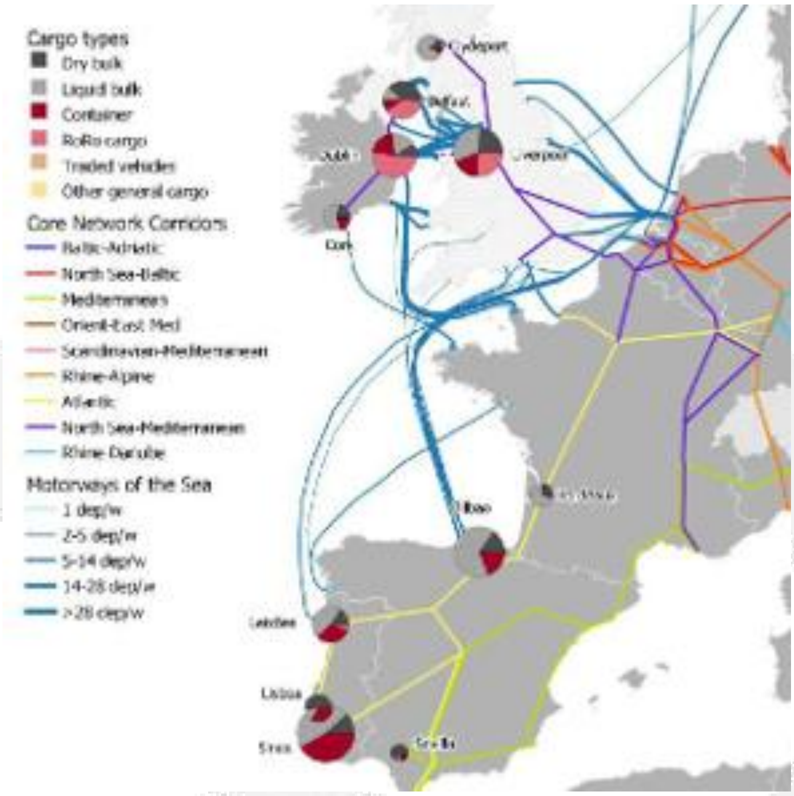

Figure 37: Core Network Corridor ports and regular ro-ro services of EU ports in the Atlantic basin, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

The second important corridor for the Atlantic Basin is the North Sea-Mediterranean Corridor, more precisely its northern part connecting Ireland and Great Britain with the European continent. Five Atlantic CNC ports are situated on the corridor: Liverpool, Dublin, Belfast, Clydeport and Cork. The maritime connection between Liverpool and Dublin is part of the corridor, but there are also many ro-ro connections in parallel, both between CNC ports (Liverpool and Belfast) and with non-CNC ports. After the United Kingdom has left the EU, these connections are now connections with a neighbouring country. There is also a maritime connection between the two corridors: a weekly link between Bilbao, Liverpool and Dublin.

Besides the connections within the Atlantic Basin, the Irish Sea ports are also connected with numerous container and roro services to ports on the continent in the North Sea basin. These direct connections may gain importance for connecting Ireland with the European mainland once the transition period for the UK following Brexit is over.

The European Atlantic Coast ports play a vital role in connecting outermost regions in the Atlantic (Canaries, Acores, Madeira, Guadeloupe and Martinique) with the continent. Due to the long distance, container traffic plays an important role for this connection. There are around 50 departures per week altogether to and from these regions (container and ro-ro combined).

3.1.4 Western Mediterranean Sea

Five core network corridors start/end in the Western Mediterranean basin. Four corridors (from East to West: Atlantic, North Sea-Mediterranean, Rhine-Alpine, and Scandinavian- Mediterranean) are North-South corridors linking the different ports of the Western Mediterranean with the European hinterland (as can be seen in Figure (38)). The Mediterranean CNC is an exemption: it stretches from the Strait of Gibraltar along the Mediterranean coast to North Italy and on through Slovenia, Croatia and Hungary to the Ukraine.

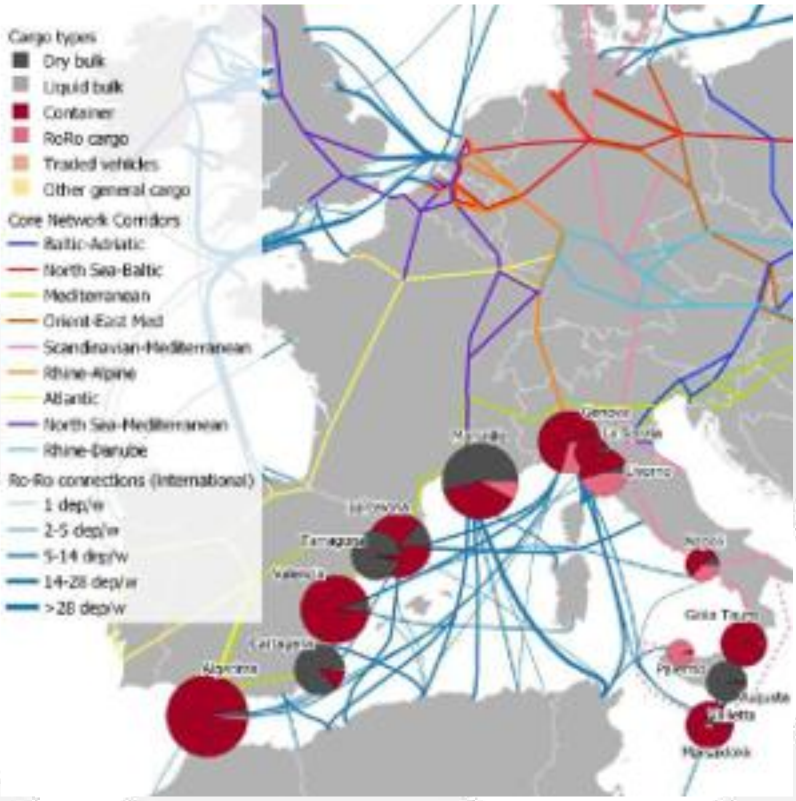

Figure 38: Core Network Corridor ports and regular ro-ro services in the Western Mediterranean, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

The various Ro-Ro connections in the Western Mediterranean CNC ports prolong the North- South corridors to North Africa. There is hence an extensive exchange between the corridors and Motorways of the Sea. The port of Algeciras provides the shortest sea distance and high-frequency services to/from Morocco. Valencia, Barcelona, Marseille and Genoa provide numerous long-distance services to Morocco, Algeria and Tunisia. Malta – the southernmost tip of the Scandinavian-Mediterranean Corridor – is connected to the continent via Italian ports. In addition, there are East-West connections between Italy and Spain, a direct alternative to land-based transport.

3.1.5 Eastern Mediterranean and Black Sea

The Eastern Mediterranean ports hosts five different core network corridors, three of which concern ports in the Adriatic Sea: Scandinavian-Mediterranean, Baltic-Adriatic and Mediterranean (see Figure (39)). The Adriatic has a dense network of ro-ro services, connecting the East coast of Italy with Croatia and with neighbouring Montenegro and Albania. In addition, there are various services connecting the Adriatic CNC ports with Greece and onwards to Turkey. For cargo coming from Western Europe, they provide an alternative to the land- based Orient-East Med Corridor for cargo to Greece.

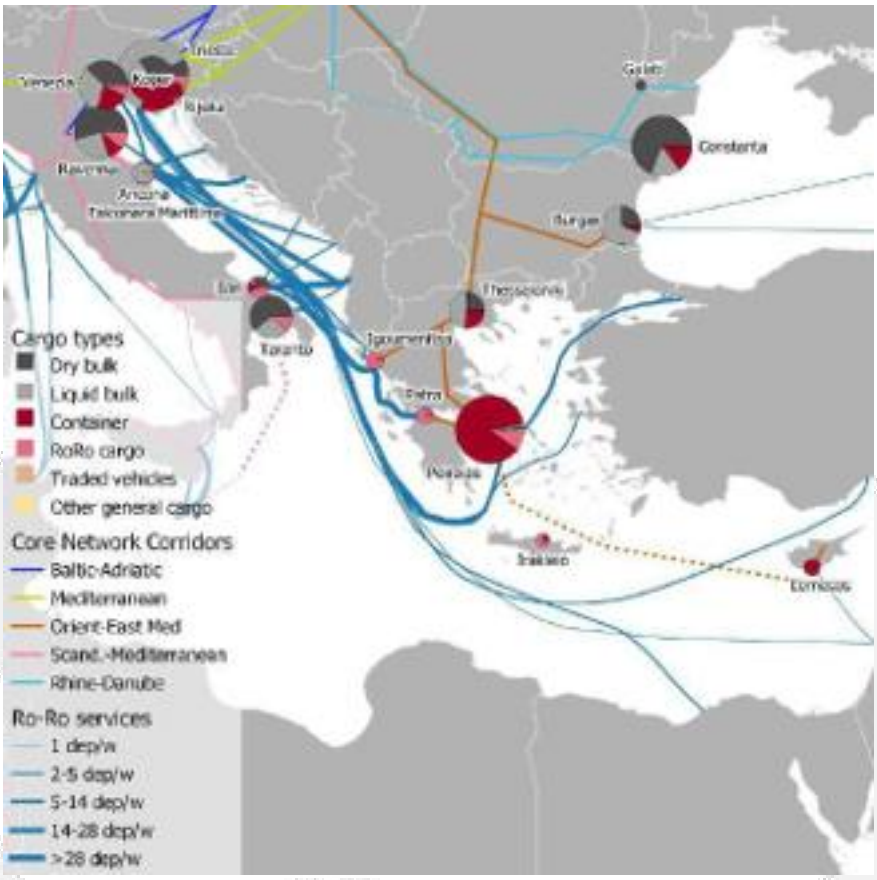

Figure 39: Core Network Corridor ports and regular ro-ro services in the in the Eastern Mediterranean and Black Sea, 2018. /Shaping the future policy of the European Maritime Space. Motorways of the Sea.

The Orient-East Med Corridor itself connects Central Europe with Greece and on to Cyprus (connected to the EU with container services, among others to/from Piraeus and Thessaloniki). Finally, the Rhine-Danube Corridor links the Romanian ports of Constanta and Galati with Central and Western Europe. The Danube is already intensively used for bulk transport while container transport only plays a minor role.

3.1.6 Outermost Regions

The outermost regions are particularly dependent on their maritime ports and the maritime connections. Due to the long distances, containerized trade is the most effective way of serving these regions. Except for the Canaries, ro-ro traffic plays no significant role for cargo traffic or only for inter-island traffic. The share of container traffic, by contrast, is higher than in any other European port range, reaching 44% on average.

3.2. Investments Needs

3.2.1 Port investment needs including sea-side and land-side infrastructure and superstructure

As it has been noted in a ship operator survey conducted in 2017, the sea approach (draught and maximum ship size) is not a major issue for short sea shipping. There are, however, capacity issues for developing rail and barge services. The necessary infrastructure needs upgrading with growing demand.

Though barges can be handled at the same quays as seagoing vessels, the latter always have priority. When capacity is scarce, barges can face severe issues and delays, which is why for instance the port of Antwerp has recently urged the major container terminals in the port to provide separate barge facilities at each terminal. The port thus wants to avoid a shift from barge to road. In general, it is estimated that there is currently a limited need to build new sea terminals for intra-European shipping beyond the ones that are already planned or under construction (e.g. in Venice). During the next 30 years, new terminal capacities may be needed in regions with significant growth of intra-European shipping, but the increase of efficiency and reconversion of existing terminals should be prioritised over new terminal constructions. It is estimated that no more than five new short sea terminal constructions or large-scale terminal extensions will be needed, resulting in an investment need of up to EUR 400 million.

3.2.2 Upgrade of ports for resilience and dual use

There are hundreds of cargo terminals in the core and comprehensive network ports that are operating on a day-to-day basis. This large terminal capacity offers the potential to reroute traffic in exceptional situations, e.g. natural disasters, accidents or other events that block neighbouring ports, or to accommodate the transport of exceptionally high or heavy cargo, projects or military equipment.

In order to estimate the investment needs, the potential demand and the necessary infrastructure for such exceptional traffic must be analysed in order to draw a map of ports and terminals that could be part of a 'resilience network'. This work can build on the work recently done by the European Commission in the context of the Military Mobility Action Plan, but should take a broader focus in order to include other exceptional traffics. A gap analysis will then be able to show investment needs in certain sea basins and coastal areas. The analysis must cover terminals and the relevant hinterland connection.

3.2.3 Investment priorities and needs for the future

Prof. Kurt Bodewig proposed the following investment priorities and needs for the future under the three new pillars which are of course closely interlinked and present important synergies amongst them:

<u>Sustainable</u>

- The focus on decarbonisation of the maritime sector points to an important need for projects innovating in ship propulsion and efficiency. The mid-term priority should be on non-fossil fuel power and long-distance capability. New engine types should also be considered.
- Deployment of alternative fuel shore-side infrastructure and bunkering vessels. Although priority is given to the deployment of zero or low carbon fuels, LNG is regarded an interim, transitionary solution for the maritime sector and still necessary for the maritime sector on its way to zero/low emission fuels (e.g. renewable or synthetic gas). Consideration for its low-carbon alternatives, such as synthetic, methane or bio-LNG, should be given where possible.
- Shore-side power supply should be further explored and developed, and capacity increased, particularly in ports situated close to densely populated areas. Persistent local air and noise emissions in particular in city ports continue to be problematic, making the case for on-shore power supply an urgent need.
- Port energy efficiency initiatives and shifting from fossil fuel based power sources to renewable energy sources should be further promoted.
- In light of the fast-changing climate conditions, emphasis must be placed on climate adaptation, to ensure the safety and good function of ports and maritime links. Of particular importance are protection measures for port resilience and climate adaptation measures, especially in exposed regions, to ensure a resilient transport network.

- Projects developing eco-incentives and innovative financial tools contributing to the sustainability of short sea shipping and further bridging funding gaps for innovative solutions such as alternative fuels need to be given further attention.

Seamless

- As regards the physical infrastructure in ports, projects that remove persistent bottlenecks in the loading operations between seagoing vessels and hinterland modes (including barge) should be highly considered. Projects that aim to develop direct hinterland connections, preferably by rail and inland waterways, and multimodal terminals are of key importance as well.
- Traffic Management and optimisation of the port call process should be further supported to gain the potential of energy efficiency in maritime transport.
- Projects to support connectivity and territorial cohesion by taking into account the needs and characteristics of peripheral regions, outermost regions and islands are needed. In parallel, revisiting the criteria for MoS projects (removal of current limitations with regard to involvement of at least one core port and one comprehensive port; allowing for intra-national connections) could prove useful and should be further explored during the revision of the TEN-T Regulation.
- Given the central role of shipping for Europe's trade connections and the growing importance of neighbouring countries in the world's economy, support for the development of maritime links with third countries are key to maintaining the prosperity of the maritime sector. Participation of the countries within the European neighbourhood should thus continue to be encouraged and regional cooperation of outermost regions with third countries be improved.

Smart

- Pursuing the interoperability between various stakeholders and data sharing systems (such as port community systems, EMSWe, eFTI, TAF/TSI etc.) is of utmost importance as to increase process efficiency. Funding digitalisation projects should therefore be aimed to avoid further fragmentation of the data sharing environment and to ensure compliance with the eMSWE, EFTI and future federated network of platforms ecosystem.
- Projects to promote efficient customs operations and cargo clearance tools continue to be of great need. National Single Windows and their integration at the EU level, taking into account the development the European Maritime Single Window environment and the progressive implementation of the new European Customs Code, continue to deserve attention.
- The further development of Sea Traffic Management by developing European wide maritime ICT services for sea traffic management, "intended route" monitoring and situational awareness should be supported in order to foster safety, effectiveness and competitiveness. Equally, real-time vessel traffic monitoring and surveillance should also be developed.

3.3. Rhine Danube Corridor

3.3.1 Achievements along the Corridor since 2014

Between 2014 and 2019, 232 reported projects have been completed along the RD- Corridor with total investment costs of € 14bn. Below in Figure (40) is a selection of key projects that have contributed to the achievement of the Key Performance Indicators (KPIs), set as targets for completion of the Corridor by 2030. These KPIs aim at measuring the progress of all nine Core Network Corridors in a comparable way and were jointly defined for each transport mode. They allow the evaluation of the recent compliance levels against the infrastructure quality targets set out in Regulation No.1315/2013, thus highlighting the progress made so far.

IWW

State	Project	KPI	Compl. Date	Costs (€)
RO	Locks modernization (Cernavoda, Agigea, Ovidiu) in 2 phases	Contribution to Good Navigation Status	06/16 06/19	104mn 122mn
RO	High Performance Green Port Giurgiu Stage II Construction (CEF co-financed)	-	03/20	16mn
EU	Fairway Danube	Contribution to Good Navigation Status	12/21	21.7mn
RS	Construction of New Žeželj Bridge in Novi Sad	Height under bridges (>5.25m)	12/15	45mn

Figure 40: Achievements along the Corridor since 2014 in IWW. / Rhine Danube. Fourth Work Plan of the European Coordinator.

3.3.2 Compliance 2019 with technical infrastructure parameters of the TEN-T guidelines by 2030

Regulation (EU) 1315/2013 lists compulsory targets to be reached for the infrastructure requirements per mode for the Core Network Corridors to be met by December 2030 at the latest. To assist the monitoring towards achieving these target values, Key Performance Indicators (KPI) are defined for all modes (as seen in Figure (41)). A compliance analysis is regularly performed to determine for each Member State along the Rhine- Danube Corridor the current and expected status of the infrastructure and the actual compliance with the standards stipulated by the Regulation.

It should be acknowledged that although infrastructure is compliant, other parameters and operational restrictions, such as safety, emission or capacity issues may still remain to be addressed, in order to reach the EU's goal of an efficient and sustainable single European transport area. This is, for example, highly relevant for improving the situation at border crossings, where long waiting times are a real obstacle for freight rail traffic (e.g. HU/RO border).

IWW compliance

KPI	AT	DE	SK	HU	RO	BG	HR	Total
CEMT class IV	100%	100%	100%	100%	100%	100%	30%	90%
Draught > 2.5 m	100%	90%	100%	100%	100%	100%	30%	82%
Bridge height	100%	45%[2]	100%	100%	100%	100%	100%	83%
RIS	100%	100%	100%	100%	100%	100%	100%	100%

Figure 41: IWW compliance rates per Member States of the European Union. / Rhine Danube. Fourth Work Plan of the European Coordinator.

- 90% of the inland waterway network, including Serbia, is classified as a class IV waterway or higher, only the Sava River is assigned to a lower class.
- A minimum draught of 2.5m is fulfilled on 82% of the inland waterways. Shortfalls relate not only to the above mentioned sections of the Sava but also to the Upper Main and the Danube between Straubing and Vilshofen (below 2m at 59% of days in 2018).

- Four bridges offer a clearance below 5.25m; 89% of the sections length complies with the requirement. Two of these bridges are on the Main (59.55 rkm, 252.32 rkm) and two on the German part of the Danube (2311.27 rkm, 2225.75 rkm).
- River Information Services are available along the Inland Waterway Core Network but to a different extent and quality. International and national exchange of fairway or traffic related data between the RIS operators is not always ensured. Activities to ensure sustainable further development, implementation and operation of infrastructure and services for harmonised RIS are ongoing (e.g. RIS COMEX), including those which are aiming to increase efficiency within inland navigation transports on the whole RD Corridor by means of increased quality and availability of fairway-, traffic- and transport information services.
- A particular challenge for the Rhine-Danube Corridor is the extent to which the targeted fairway depth is met. This relates to the concept of a 'Good Navigation Status', which aims at enabling efficient, reliable and safe navigation in addition to meeting purely technical parameters. But the achievement of targeted depths varies dynamically as it depends not only on the waterway infrastructure conditions, but mainly on the hydrologic circumstances.
  The project FAIRway Danube identified the following sections as highly critical in terms of maintenance and rehabilitation given the gap between available water levels and actual fairways depths: the Hungarian Danube, the area around Milka/Belene/Coundur (BG) and Cochirleni (RO).

Port compliance

KPI	AT	DE	SK	HU	RO	BG	HR	Total
Inland ports								
Rail connection	100%	100%	100%	50%	83%	100%	100%	89%
CEMT connection	100%	100%	100%	100%	100%	100%	100%	100%
Clean fuels	50%	0%	0%	0%	0%	50%	0%	5%
Term. availability	100%	100%	100%	100%	100%	100%	100%	100%

Figure 42: Seaports & Inland Ports' compliance rates by Member State. / Rhine Danube. Fourth Work Plan of the European Coordinator.

The main findings from Figure (42) are as follows:

- All 19 ports comply with the CEMT IV class connection KPI and with the KPI requirement to have at least one freight terminal open to all operators in a non-discriminatory way and application of transparent charges.
- 17 of them have rail connection, except Komarom (HU) and Cernavoda (RO).
- Currently, 18 out 19 ports do not have supply alternative fuels. At the moment, only the Port of Ruse (BG) has LNG bunkering facilities (since 2016). In addition, the Port of Enns (AT) has LNG fuel supply facilities since 2018, but currently only for trucks as ships cannot berth on the

water side of the facility, and the facility does not have the necessary equipment to supply LNG to vessels.

3.3.3 Persisting bottlenecks and missing links (compliance by 2030)

A dense pipeline of on-going and planned infrastructure projects along the RD Corridor has been presented. However, persisting bottlenecks and missing links still exist and projects are not planned to tackle them.

IWW network bottlenecks

Navigation reliability (or good navigation status) is the decisive parameter for IWW. It is expected that a good navigation status is only partially reached throughout the Corridor. Within the current financial perspective, a number of actions have been funded through CEF along the main cross-border sections in Hungary, Croatia, Slovakia, Bulgaria and Romania. These Actions aimed in particular to ensure that all environmental permits have been acquired to start the works for the upgrade after 2022. Therefore numerous works projects or studies along these cross-border sections are foreseen from the start of CEF II.

The CEF funded action FAIRway Danube monitors the waterway conditions and analyses their changes over the years. The action includes the following steps:

- Update national action plans regularly.
- Concerted purchase of advanced equipment for hydrological services.
- Carry out pilot activities regarding new technologies and innovative solutions.
- Identify innovative approaches for fairway rehabilitation and upgrade.
- Prepare documentation for implementation of future selected measures that further support the deployment of the "Fairway Rehabilitation and Maintenance Master Plan".

A CEF funded Action along the cross-border section between Sava in Croatia and BIH aims at obtaining all environmental clearances to start the works in the future.

Intentions to increase the bridge clearance are missing for all of the bridges not complying with the Regulation. Two of the bridges (Alte Mainbrücke, Würzburg; Rail Bridge Bogen, rkm 2311.27) can represent a particular challenge for the navigation of passenger vessels and would also represent an obstacle if container transport on the Danube develops. However it has to be noted that the 12th century Alte Mainbrücke in Würzburg is a landmark of the city. Therefore possibly this issue cannot be solved due to the particular historic value.

A key element for inland waterways to be more and more a real alternative to other transport modes is the removal of administrative barriers and improve institutional capacities to tackle major societal changes. The barriers and procedures that most affect IWT were identified in the Danube Transnational Programme (DTP) Interreg project DANTE (http://www.interreg- danube.eu/approved-projects/dante).

The work carried out in the framework of the EU Strategy for the Danube Region (Priority Areas 1a on Inland Waterways and 11 on Security) meanwhile resulted in practical solutions for simplified and harmonised border-crossing procedures along the Danube waterway. The synchronised application of a first set of so-called Danube Navigation Standard Forms (DAVID) was started in spring 2020 with their introduction in Hungary, Croatia and Serbia.

The main objectives regard to increased institutional capacity in Danube navigation by boosting joint transnational competences and skills in education and public development services were identified in the DTP Interreg project Danube SKILLS (http://www.interreg-danube.eu/approved-projects/danube-skills).

The next element on which IWW have to focus in the future is a fleet modernization, especially the Danube fleet. The fleet modernization aims to achieve a higher acceptance and use of IWT as an environmentally friendly transport mode contributing to economic growth and a more sustainable transport system in the Europe as demonstrated in Figure (43).

Figure 43: IWW compliance by 2030 overview. / Rhine Danube. Fourth Work Plan of the European Coordinator.

Port Compliance

Lack of functional railway connections are key bottlenecks for the port development. Such railway connections are currently missing in the Hungarian port of Komarom and Romanian port of Cernavoda. In addition, the lack of alternative fuels supply facilities in all but one port is a situation that needs to be tackled in the future project pipelines.

Clean Fuels: At the moment, inland ports do not have facilities for alternative fuels supply, but the Port of Budapest plans an LNG bunker station at the end of 2019 and the Port of Bratislava plans to complete similar facility in 2025. Completion of LNG bunkering station for vessels in the Port of Enns is planned for 2030.

Administrative barriers in inland ports:

The list below clarifies the most relevant administrative barriers for ports which exist along the Corridor:

Non-harmonized processes and different documents related to the vessel, its cargo, crews, passenger and vessel provisions in a number of cases cause additional administrative work by vessel operators and skippers, thus delaying and prolonging the process of vessel reporting at borders or in ports, especially when loading/unloading or just transiting third (non-EU) countries.

Different charging practices between Member States are also affecting the smooth transport. Due to different port administration models applied in various Member States, some ports are charging their infrastructure fees based on the load a vessel is loading/unloading, while some ports are charging the same fees based on the vessel capacity, vessel length, sometimes including the time component in the fee calculation. It has been noted that the various charging systems sometimes cause confusion and losses in profits of ship operators and/or shippers/receivers of cargos. This is sometimes caused by insufficient information on port charges needed for various freight and voyage calculations (freight rates, operating costs, etc.).

Lack of coordination for putting up projects involving multiple authorities: in some Member States, infrastructure managers identified difficulties in preparing/defining projects that need to involve different authorities within a port area (e.g. port authorities and rail authorities managing intraport railways) and beyond a port area. The latter refers to situations when, for example, upgrading a railway link is of lower importance for railway authorities, but it is of high importance for a port.

The situation on compliance with port KPIs expected in 2030 is given in Figure (44) below.

Criteria	CEMT IV Class connection	Rail connection	Alternative clean fuel supply facilities	Min 1 common user terminal
Port	Compliance Y/N			
Frankfurt A/M (DE)	Y	Y	N	Y
Nürnberg (DE)	Y	Y	N	Y
Regensburg (DE)	Y	Y	N	Y
Enns (AT)	Y	Y	Y	Y
Vienna (AT)	Y	Y	N	Y
Bratislava (SK)	Y	Y	Y	Y
Komárno (SK)	Y	Y	N	Y
Komarom (HU)	Y	N	N	Y
Budapest (HU)	Y	Y	Y	Y
Vukovar (HR)	Y	Y	N	Y
Slavonski Brod (HR)	Y	Y	N	Y
Drobeta TS (RO)	Y	Y	N	Y
Calafat (RO)	Y	Y	N	Y
Giurgiu (RO)	Y	Y	N	Y
Galati (RO)	Y	Y	N	Y
Cernavoda (RO)	Y	N	N	Y
Vidin (BG)	Y	Y	N	Y
Ruse (BG)	Y	Y	Y	Y

Figure 44: Expected situation with inland ports compliance in 2030. / Rhine Danube. Fourth Work Plan of the European Coordinator.

As far as seaports are concerned, the Rhine – Danube CNC has only one seaport: the Port of Constanta. This port complies with all KPIs except for the alternative fuels supply facilities. Nevertheless, the port authority plans to provide such facilities by the end of 2023.

3.3.4 Transport Market Study

The Corridor scenario

The objective of the Multimodal Transport Market Study (MTMS) is to determine the impact of implementing the projects in the Work Plan Project List on the Corridors network. The MTMS provides an estimation of the prospective traffic flows on the Corridors in 2030, while also offering a view on the associated effects on the GDP and the labour market. It does so by considering two different scenarios, the Baseline Scenario and the Reference Scenario. The Baseline Scenario assumes that the implementation of the core TEN-T network stops at the end of 2016 and no further investments are made. In the Reference Scenario, the core TEN-T network is assumed to be fully implemented by 2030, in line with the requirements of Regulation 1315/2013 on the development of the TEN-T.

In addition to the Baseline and Reference Scenario, a third scenario is defined unique to each corridor. Referred to as the Rhine-Danube Corridor Specific Scenario, this scenario highlights the effects of a certain change that impacts the Corridor. For the scenarios relating to full corridor completion, this work plan draws on the results of the study the impact of TEN-T completion of growth, jobs and the environment published in 2019 by the European Commission. The corridor-specific scenario was instead elaborated as part of an additional study conducted in view of the of this work plan.

Reference and Baseline scenario

The impact analyses performed under the Growth and Jobs study allow capturing the direct effects of the new infrastructure developments in the transport sector and the indirect effects on supplying industries and the wider economic impacts induced by mechanisms such as higher productivity diffusing to other economic agents and into future years at regional/national scale. For the Rhine-Danube Corridor, according to this study, the implementation of the whole EU-wide core TEN-T (reference vs. baseline in 2030) will result, in the corridor Member States during the period 2016 - 2030, in an increase of about € 813 billion, and in the generation of a total of 2.3 million additional man-years of jobs.

These socioeconomic gains will be furthermore coupled with additional benefits in terms of reduction of external costs and environmental protection. The planned investments along the corridor, in accordance with the present work plan (notably in the field of rail and the improvement of intermodal transport) will enhance the environmental performance of the TEN-T, creating favourable conditions to increase the modal share of greener transport modes, mitigating greenhouse gas emissions, noise and, as appropriate, other negative environmental impacts.

Whereas the transition to innovative and sustainable transport technologies will generally make possible the decarbonisation of all transport modes, a positive contribution is also expected from the large-scale adoption of alternative clean fuels and zero-emission vehicles. The ongoing and planned projects on the TEN-T are expected to play an important enabling role by supporting the early adoption of such technologies.

Corridor specific scenario

The Rhine-Danube Corridor Specific Scenario investigates the impact on the RDC if various key projects from TEN-T project list are being implemented later than 2030. The selected projects concern all modes of transport with a focus on projects on the Eastern part of the corridor. Under this scenario, sixteen projects representing 9.6% of the total TEN-T investments on the corridor will be delayed and not be completed before 2030, meaning that transport time and cost savings will not been achieved.

Accumulated losses of GDP would amount to € 12 billion and 148,000 job-years would not be created. The impact on GDP and employment in relative terms is very small and of comparable magnitude with results of other corridors specific scenario’s. At country level, the impact depends on the size of non-implemented TEN-T projects and on its relation to national GDP and to total investments. Moreover, productivity and demand impulses from TEN-T investments cause stronger impacts in less developed countries. Therefore, the relative impact is most noticeable in Czech Republic, Romania and Slovakia.

The member states not directly affected by non-completion of projects – France, Hungary and Austria – would experience (slight) positive effects on GDP due to productivity gains based on shifts in traffic and investments. The latter applies in particular to France.

3.3.5 IWW & inland ports including RIS deployment plan and Maritime Ports on the RD Corridor, interactions and complementarity with the MoS Coordinator Implementation Plan for the RD Corridor

The projects which have been implemented at National level or funded through the EU, in particular via ESIF and CEF funding addressed existing difficulties that limit admissible draughts or hinder the achievement of target fairway depths. Targeting 6 major bottlenecks, the other CEF-funded IWW projects concentrate mainly on three areas of intervention: upgrade and construction of infrastructure, studies with pilots addressing environmental concerns and the implementation of RIS along the whole Danube.

Several bottlenecks resulting in unreliable, unsafe and non–compliant navigation infrastructure are being tackled through works actions, namely: the reconstruction of the cross-border Komárno-Komarom Bridge (2014-EU-TMC-0485-W) and Upgrade of Gabcikovo lock (2015-SK-TM-0151-W) or the upgrade of the inland ports of Giurgiu (2014-RO-TMC-0313-W) and Galati (2015-RO-TM-0275-W).

The other group of Actions aims at ensuring a long term good navigation status side by side with a good ecological status (GES) along three stretches of the Danube and the Sava rivers: the Romanian-Bulgarian and Hungarian-Slovakian common sections (Actions 2014-EU-TMC-0297-S and 2016-SK-TMC-0263-S, respectively) as well as the Croatian Sava (2014-HR-TMC-0122-S). The studies and consultations for obtaining the EIA decisions and all other necessary environmental assessments have started in all countries in line with the integrating guiding principles of the International Convention of the Protection of the Danube River (ICPDR). Civil society and environmental stakeholders have been associated to the implementation of the Actions.

Operational bottlenecks are being addressed through RIS-related pilot Actions involving all Danube riparian countries (2014-HU-TM-0619-W and 2015-EU-TM-0038- W, 2015-EU-TM-0036-W). Their objectives are the promotion of a more transparent and effective data exchange process and the simplification of complex administrative procedures. By end of 2018 the overall Corridor RIS concept and architecture option were approved by the beneficiaries.

The majority of these projects are not related to works, but to studies. They will pave the way for the future works to be funded in the next financial perspectives. For the countries along the Danube, the EU support is essential, not only from a financial point of view, but from a political one as well. Coordinators have been extremely active in supporting the countries to work together to find sustainable solutions and consensus, while reaching out to the many different stakeholders. The involvement of NGOs in these projects has been essential to develop an integrated approach to ensure good navigation status while preserving the good ecological status.

In the Northwestern part of the Corridor, the plan approval decision for the section Straubing-Deggendorf was issued in 12/19. For the critical section Deggendorf – Vilshofen plan approval procedure started in 2018, but is still ongoing. Objective is to enhance navigability conditions by increasing fairway depth by 25cm to 2.25m at Low Navigable Water Level (LNWL)5. Although not fully in line with the requirement of Article 15 of the TEN-T regulation that forsees the minimum requirement of draught of 2.5 m, this will be a significant improvement for IWW transport.

Work is on-going between Slovakia and Hungary to address the common section and to finalise a feasibility study which will harmonise works interventions for both countries to tackle existing bottlenecks. This future work project will not consider the existing locks or the construction of new ones in this section. Slovakia wants to follow up on a feasibility study of Lower Vah navigability in the section Piestany – Komarno (rkm 113,40 – rkm 0,00), which was elaborated as a part of the implementation of action 2014-EU-TMC-0231-S, and elaborate a detailed feasibility study of the river Vah navigability in sections not included in the previous feasibility study - these sections are Piestany – Trencin and Trencin – Zilina. The river Vah is part of the TEN-T Core Network (between Zilina and Komarno) and connects the Baltic-Adriatic Corridor with Rhine-Danube Corridor in Komarno. The FAST project between Bulgaria and Romania (funded through CEF) is on-going and planned to be completed by end 2021. Discussions are on-going between the two countries on the governance structure of a future project and how the funding and financing decisions should be taken. The Rhine-Danube Coordinator is very involved in both processes and supports both countries in their work.

The Sava river in Croatia needs to be upgraded with regard to CEMT class requirements and the minimum draught of 2.5m. Croatia is currently working on finalising a final design for the Croatian section and the common section with Bosnia Herzegovina in order to obtain decisions and permits for a future work project to address this situation. Cooperation is on-going with Serbia for both the Danube and the Sava.

Although not yet in the Corridor, the CEF funded Iron Gate I Action is on-going and will be finalised end of 2021. Serbia is extremely active in the field of IWW and strongly appreciates the CEF support including the involvement of the Coordinator in these projects.

In inland ports, two ports (Komarom and Cernavoda) need to provide railway connection to the hinterland, although no such project is foreseen in the planned project pipeline. For this reason, the study team suggested two additional projects to cover these missing links. Furthermore, since only 4 ports would comply with the requirement of provision of alternative fuels supply facilities by 2030 (Ruse, Budapest, Bratislava and Enns), 14 additional projects for construction of alternative fuels supply facilities have been suggested in the category of “additional” projects, in order to cover the lack of such facilities in 14 ports.

The Core Network Corridor must be developed in line with growing demand in the different cargo segments. The Rhine-Danube Core Network Corridor shall:

- Make sure to provide the necessary rail capacity to and from ports in the Black Sea.
- Work together with ports, forwarders and ship operators to improve the administrative procedures and data flow across all modes.
- Assure the reliability of the network in order to guarantee the smooth flow of goods between MoS and the Corridor and avoid delays.

4. PHASE 3 – ASSESSMENT OF AVAILABLE INFRASTRUCTURE

The strategical locations and the number of batteries required at each charging station out of the different possibilities will be determined based on an optimization process, as described in Chapter 5, which is dependent on a set of factors (e.g. the number of batteries that can be accommodated in land and onboard, vessels sailing profile, charging time, battery capacity, and the vessel's power requirements). The final decision is to be made from a set of possible combinations identified where the ultimate criteria for the decision will rely on availability of the necessary resources/infrastructure for the CD solution and the associated implementation and operational costs.

The charging station costs are dependent on the cost of the land and building (location costs) and electricity supply - power capacity. This chapter, focuses on the understanding of the available facilities at pre-identified locations along the Rhine and the Danube and on the charges applied for battery systems at these locations.

4.1. Facility Assessment

4.1.1 Rotterdam Port Facilities

The Port of Rotterdam has tank storage capacity of over 30m cubic metres, crude oil storage capacity of 12m cubic metres and mineral oil products storage capacity of 6.7m cubic metres. It also facilitates independent storage of mineral oil products, chemical products, and vegetable oils and fats.

The port includes 122 jetties and 23 berths, and has six pilot boats and 29 tug boats. There are over 90 terminals, 35 reserved for liquid bulk cargoes, 15 for dry bulk cargo and 17 for multi-purpose use.

The port has nine container terminals to handle short-sea, deep-sea and inland shipping. Other terminals at the port include seven roll-on/roll-off, three juice, two fruit terminals, and one each for steel and paper, cars, and cruise vessels.

The port also has a unique hospital with special accommodation arrangements for seamen of all ranks and nationalities.

Equipment

Cargo-handling equipment at the Port of Rotterdam includes ten sheer leg cranes, 12 container cranes, 22 ship-to-shore bulk cranes, 25 floating cranes, 103 container gantry cranes, and 162 multi-purpose cranes.

The port has three shipyards. There are five graving, one graving and covered, and seven floating docks. A slipway maintains inland vessels.

Berths availability

The maps show the berths for inland shipping in Rotterdam and the Drecht cities. The maps indicate the ships' maximum allowable length and the maximum number of ships allowed. The markings printed on the maps indicate the type of ship allowed to moor at that particular berth. The indication 3x>95 for example, means that a maximum of three ships longer than 95 meters are allowed to moor there. The indication B<35 means that only ships up to a combined width of 35 metres are allowed to moor there. The traffic signs on the map are part of the Inland Waterways Police Regulations. At some berths, ships are exempt from carrying anchor lights.

URL
https://portofrotterdam.maps.arcgis.com/apps/webappviewer/index.html?id=2b0a8d71f471495c9d48002b7bb9c100

4.1.2 Antwerp Port Facilities

The Port of Antwerp is well accessible through a multimodal transportation network consisting of road, barge, rail, pipelines and short sea / feeder. The port is divided into two areas, the Right Bank and the Left Bank. Right Bank facilities include the Berendrecht Lock, the Bonaparte Dock, the Amerika Dock, the Albert Dock, the Delwaide Dock, the Europa terminal, the North Sea terminal and the MSC home terminal.

“Antwerp is the lead breakbulk port in Europe and a base for forwarding companies.”

The Berendrecht Lock measures 500m in length and 68m in width, and is the largest lock in the world. The Left Bank features the Kallo Lock, the Verrebroek Dock, the Vrasene Dock and the Deurganck Dock. The port has 160km of quayside available for loading and unloading activities.

The port also features a petrochemical cluster, which has five refineries with an annual distillation capacity of over 40 million tons.

Two large refineries are connected with the Port of Rotterdam through the Rotterdam-Antwerp Pipeline (RAPL), which ensures the continuous supply of crude oil. The port offers over 5.3 million square metres of covered storage space.

Equipment

The Port of Antwerp has three floating cranes and over 30 dock-mounted cranes. The floating cranes include Brabo with a capacity of 800t, and Portunus and Titan with a capacity of 45t. The dock crane department operates mobile cranes.

Shore Power

Port of Antwerp and the City of Antwerp offer skippers a large number of shore power connection points in the port of Antwerp. This network allows barges to consume electricity via the quayside while they are moored in the waiting dock.

In cooperation with partners, a uniform shore powersystem has been developed for inland navigation in Flanders. Currently there are 3 shore power locations managed by the Antwerp Port Authority.

Shore power can be found at the locations below:

Waiting dock for barges at the Noordkasteel

7 cabinets (max. 63A) for inland barges at quay 75

2 cabinets (max. 125A) for tanker transport at quay 85-87

Waiting berths Kanaaldok B2

14 cabinets with 3 connection points each (2 max. 63A + 1 max. 32A)

Kattendijkdok-Westkaai

3 cabinets (max 400A) for river cruises at quay 15 & quay 16

The shore power cabinets at Kattendijkdok-Oostkaai, Asiadok and Willemdok are managed by the City of Antwerp.

4.1.3 North Sea Port Facilities

North Sea Port offers various facilities throughout the port area to make a ship's passage and stay in the ports as comfortable as possible.

For example, the port provide current berth information by means of an interactive map. In it will information like the function of the berth or the maximum draught in that location can be found.

To focus on improving the air quality in the port and to fight noise pollution, various shore power boxes are available.

Berths availability

Various berths are available in North Sea Port such as :

Outer harbour (Vlissingen)

Vlissingen

Braakmanhaven (Terneuzen)

Terneuzen

Gent

Below you will find an overview of the map per area:

URL
https://northseaport.maps.arcgis.com/apps/webappviewer/index.html?id=197cb2d9ae494637b6540894ae8bb1de&center=3.598,51.447&level=15

Shore Power

North Sea Port offers various services throughout the port area to make a ship's stay in the ports as comfortable as possible. This includes the availability of shore power facilities in various locations.

Various shore power boxes are currently available at North Sea Port. The shore power facilities are provided by North Sea Port and Parkline.

You can view an overview of all the shore power points on an interactive map :

URL
https://northseaport.maps.arcgis.com/apps/webappviewer/index.html?id=197cb2d9ae494637b6540894ae8bb1de%20

Wi-Fi

North Sea Port offers various services to make a ship's stay in the ports as comfortable as possible. In Vlissingen and Terneuzen, wifi is available in a number of locations.

For inland skippers, free wifi is available for 48 hours in several locations. After an online application, the wifi is directly available and secured by encrypting the wireless connection.

4.1.4 Hamburg Port Facilities

The port features four large container terminals capable of high-performance handling. Three of the terminals are operated by Hamburger Hafen und Logistik (HHLA), a port logistics group based in Europe. Capacity of the terminals is being continually expanded to meet the growing demands for cargo handling.

HHLA Container Terminal Burchardkai is the Port of Hamburg's largest cargo handling facility. The terminal features nine berths and an area of 1.4 million square meters. For container handling, there are 30 gantry cranes. About berth information, there are 10 quays, with max ship length 400m and max ship width 56m .

It is equipped with 27 container gantries, including modern Twin-Forty container cranes which are capable of loading or unloading two 40-foot containers in a single movement.

Maximum depth is 15.3m and quay length is 2,850m. The terminal will be expanded in the future to enable it handle 5.2 million twenty-foot equivalent units (TEU).

HHLA Container Terminal Altenwerder began operations in 2002 as a joint venture between HHLA and Hapag-Lloyd. The terminal is spread over an area of one million square meters and has four cargo berths. Maximum depth is 16.7m and length of quay is 1,400m. The terminal features 15 container gantry cranes. About berth information, there are 4 quays with 1400m length of quay, with max ship length 400m, max ship width 52m and max depth 16.7m .

The Eurogate Container Terminal Hamburg features six berths and a quay length of 2,080m. Maximum depth is 15.3m and terminal area is 1.2 million square meters. Operated by Eurogate Group, the terminal is equipped with 24 container cranes. At present there are eleven block-train tracks and eight rail mounted crane-bridges available for loading and discharging container waggons. For container handling, there are 24 gantry cranes with 66 tones lifting capacity.

HHLA Container Terminal Tollerort has an area of 600,000m2 and four container berths. Maximum depth is 15.2m and length of quay is 1,230m.

The terminal is equipped with 12 container cranes. It features its own container rail station which has been operational since 2008. The station has 720m of track and three Transtainer cranes capable of handling block trains efficiently.

The Port of Hamburg also features 42 multipurpose terminals capable of handling general cargo and bulk cargo. The general cargo terminals handle cargo such as vehicles, fruits, metals, iron, paper and cardboard. Some of these terminals include Wallmann Terminal, C. Steinweg Süd-West Terminal and Rhenus Midgard – Dradenauhafen. The port handled 2.6mt of general cargo in 2010.

"Port of Hamburg, the largest seaport in Germany, lies between the North Sea and the Baltic Sea."

Bulk cargo terminals are also available at the port and are equipped with grabs, suction equipment and conveyors. The port handled 40mt of bulk cargo in 2010.

Companies handling bulk cargo at the port include Vopak Dupeg, Hansaport Hafen, Kalikai, G.T.H. Getreide Terminal Hamburg and Rhenus Midgard.

The port's cruise terminals include Cruise Terminal HafenCity and Cruise Terminal Altona.

Cruise Terminal HafenCity has two berths. Length of quay is 460m and maximum depth is 12m.

Cruise Terminal Altona opened in June 2011 and features one berth. Terminal area is 1,500m2 and quay length is 360m. Maximum depth is 10.6m.

4.1.5 Constanţa Port Facilities

In Constantza Port there are four container terminals, which offer modern facilities and operating conditions for portcontainer vessels.

SThe direct service lines launched in the last years between Constantza Port and ports in the Far East have turned the port into a distribution centre for the Black Sea region and Central and Eastern Europe, serving the neighbouring ports through feeder ships.

The largest specialised container terminal at the Black Sea was inaugurated in Constantza Port at the end of 2003, being operated by Dubai Ports World. Due to its quay depths, of minimum 14.5 m, the terminal can operate Post-Panamax type container vessels, ensuring with its operating facilities an efficient handling rate for the moored vessels.

The terminal's main berth length is 636 m, the feeder berth's length is 411 m and the covered storage area is 5,000 sq.m.

Also, the terminal offers full rail coordination services, with three railway lines, each with a length of 616 m, capable of handling at the same time 3 trains, with 30 wagons each.

Due to its facilities, large depths and quality services, the Port of Constantza has registered in 2007 a container traffic of 1,411,387 TEU, which represents a record in the Black Sea region.

Container service lines have been opened on the Danube starting with 2005, linking the Port of Constantza with river destinations like Giurgiu, Belgrade and Budapest.

4.1.6 Duisburg Port Facilities

Equipment

The Port of Duisburg has 16 forklifts, 3 to 37 t, 1 container forklift, 1 x 40 t crane, 2 x 32 t crane, Special equipment such as cross braces, hooks, etc.

4.1.7 Cologne Port Facilities

Equipment

The Port of Cologne Godorf has 3 cranes and 3 harbour basins. Port of Cologne Niehl I has 4 harbour basins, 12 own crane systems and 1 company crane. Port of Cologne Niehl II has 1 harbour basin.

4.1.8 Karlsruhe Port Facilities

Equipment

The Port of Karlsruhe has 19 container bridges and revolving cranes 4 to 25 t. Port of Karlsruhe has 2 container cranes 50 t, 1 heavy cargo handling area (Goliathplatz), 1 Ro-Ro ramp for loading in high and low water. Furthermore, Port of Karlsruhe has 2 grain silos with maize drying facilities and dust-free loading equipment for HGVs, rail and ships, various truck-mounted cranes 20 to 250 t. It also has 1 carbon ribbon loading system for railcars, 1 calcinate silo with HGV, rail and ship loading facilities, 7 loading systems for mineral oil. The Oil Port has 6 loading systems for mineral oil and 1 handling system for liquid gas.

4.1.9 Ludwigshafen Port Facilities

Equipment

The Port of Ludwigshafen has 2 container bridges with 62 t at the hook, 1 gantry crane for railway handling (52 t at the hook) and 9 crane facilities lifting capacity up to 25 t. A mobile port crane lifting capacity 104 t, 1 hydraulic excavator, 3 belt conveyor systems with conductor pipe, 1 bulk and suction pipe and finally 19 risers with liquid handling arms/pipes.

4.1.10 Amsterdam Port Facilities

The Port of Amsterdam is a multifunctional port capable of handling, storing and shipping cargoes ranging from cocoa beans to coal, and from paper to oil. The port is served by three types of terminals for breakbulk, containers and energy.

The Koopman Car Terminal has a surface area of 350,000m2. Its maximum depth is 12m and quay length is 350m. Automotive stevedore and RO/RO activities are performed here.

The Amsterdam Marine Terminal handles containers, RO/RO and general cargo. Its quay length is 210m and maximum depth is 10.5m.

The Amsterdam Container Terminal has a total surface area of 620,000m2. Its quay length is 645m and maximum depth is 15.5m. The terminal is served by five 100mt gantry cranes.

The VCK Terminal, located in Suezhaven / Beringhaven, is an all round logistic service provider. It has a total surface area of 175,000m2 and is equipped with a 55t crane. The Waterland Terminal is also located in Westhaven. Its covered surface area is 77,500m2 and open area is 110,000m2. The terminal is equipped with three gantry cranes.

BP Amsterdam Terminal has a total surface area of 880,000m2 and maximum depth of 14.6m.

Berth Availability

In the port area, there are a limited number of public waiting berths available for:

Non-cone vessels, non-cone vessels (smaller than 70 metres), cone vessels, torque links, barges, tug and tow boats

Actual occupation of the waiting berths (BLIS):

URL https://blauwegolfverbindend.nl/kaart/13/52.40461/4.87688?2

Waiting berths and facilities on the port map:

URL https://www.portofamsterdam.com/en/shipping/inland-shipping/port-map-inland-shipping

Map for push barge berths:

URL

https://www.portofamsterdam.com/en/shipping/inland-shipping/poseidon-digital-tracking-push-barges

Shore Power

Port of Amsterdam has provided shore power connections at various berths for inland navigation and passenger vessels. This is good for the environment and the use of ship-to-shore power also prevents noise pollution.

URL https://www.portofamsterdam.com/en/shipping/inland-shipping/facilities#kaart

Wi-Fi

There are two WiFi hotspots in the port of Amsterdam:

In the Houthavens

At the ADM port

URL https://www.portofamsterdam.com/en/shipping/inland-shipping/facilities#kaart

4.1.11 Marseille Port Facilities

The port of Marseille offers the longest quay in Europe: 2.6 linear km operated by two terminals, the Terminal de la Méditerranée and the Fos2XL Terminal. Furthermore, the port includes the largest container terminal in France: The Terminal de la Méditerranée with a capacity of 1.5 million TEU operated by Eurofos/Portsynergie. Also, port of Marseille offers a new generation equipment with the largest gantry cranes in the world and hybrid straddle carriers.

Equipment

The Mediterranee Terminal has 8 gantry cranes. The Seayard terminal has 6 gantry cranes

4.1.12 Liege Port Facilities

The Port of Liege's first rate facilities are linked to the Liege region's outstanding river, road, rail and airport network. The Liege Port Authority is admirably suitable for loading, unloading, storage and handling all kinds of goods: construction materials, ores, bulk goods, chemicals, steel, farm and petroleum products, general merchandise and containers. The port of Liege offers regular direct links with the United Kingdom for coastal vessels of between 1,000 and 2,500 t .

Equipment

The Port of Liege offers 28 km of quay berthing. 96 cranes and gantry cranes, 38 weighbridges and 3 container terminals.

4.1.13 Strasbourg Port Facilities

Equipment

The Port of Ludwigshafen has 2 trimodal container terminals with 5 gantry cranes, 1 460-t heavy duty gantry crane, numerous loading stations and Eurofret road haulage centre. The port of Lauterbourg has a trimodal container terminal with 1 gantry crane and a 220 heavy duty gantry crane.

4.1.14 The Swiss Port Facilities

Equipment

The Swiss Port has 4 trimodal container terminals and silos for 385,000 m^3 of grain. Additionally, it has 80,000 m^3 of other bulk cargo storage areas and storage tanks for 1,250,000 m^3 of liquids. Finally, 60 cranes with a lifting power of 5 to 300 t and 12-20 landing stages for cabin ships

4.1.15 Summary Table of Ports Facilities

Figure (45) shows a summary table of already available Port Infrastructure.

		Container Bridges		Container Cranes		Mobile Cranes		Notes
Country	Port	Number	Lifting Capacity (tonnes)	Number	Lifting Capacity (tonnes)	Number	Lifting Capacity (tonnes)	
Germany	Duisburg			21	55	1	110	8 container terminals
Germany	Karlsruhe	19	4 to 25	2	50	-	20 to 250	
Germany	Ludwigshafen	2	62	1	52	1	104	9 crane systems (25 tonnes)
Germany	Manheim	4	-	1	50	52		2 trimodal container terminals
Germany	Kehl	3	For bulk cargo (22, 25, 50)			6	26.5	
		3	or container traffic (38, 42, 50)					
Germany	Weil am Rhein			1	-	1	-	
Germany	Hamburg			30	110	1	140	
Germany	Cologne			3	-			
France	Strasbourg			5	Gantry Cranes	4	Gantry Cranes	2 trimodal container terminals
France	Lauterbourg			1	Gantry Crane			trimodal container terminal
France	Colmar			1	40 Gantry Crane			
France	Mulhouse			3	40, 50, 60 Gantry Cranes			2 container terminals
Switzerland	Basel			2	34	1		
Belgium	Antwerp			2	41			5 container terminals
Romania	Constanța			5	Post-Panamax Cranes	3		

Figure 45: Table of Ports Infrastructure.

4.2. Electrical Regulations and Pricing Policies Assessment

For the commercialization of the Current Direct solution, it is necessary to guarantee that the CD solution complies with the standards and existing regulations for electric battery system connections as well as to guarantee that electricity supply for the battery charging station is available in strategical locations. The charging station operational costs include:

- Energy purchase from power supplier (electricity tariffs)
- Network costs for connection to the grid
- Logistical costs for the loading, unloading and transportation of the batteries to and from the vessel
- Operational costs for maintenance, insurance, among others.

A preliminary assessment of the main standards and regulations, current grid infrastructure and future plans for electrification of the main locations (ports and locks on an initial stage) along the Rhine and the Danube rivers was performed. To start, six port locations– Port of Rotterdam, Port of Amsterdam, Port of Antwerp, Port of Constantza, Port of Galati and Port of Bratislava – and the main locks along the Danube and the Rhine were assessed.

4.2.1 Main Standards and Regulations for Battery Systems

The Current Direct infrastructure, as previously identified in the scope of WP2-T2.4 – Onshore Requirements, must comply with International Standards that represent the technical agreement between Authorities and companies. In this subchapter, the requirements relating to the electrical infrastructure have been identified:

IEC/ISO/IEEE 80005-1:2019 – Utility Connections in Port. Part 1: High Voltage Shore Connection (HVSC) systems. General requirements [1] comprises the design, installation and testing of HVSC systems and addresses: HV shore distribution systems, shore-to-ship connection and interface equipment, transformers/reactors, semiconductor/rotating frequency converters, ship distribution systems, and control, monitoring, interlocking and power management systems.

IEC/ISO/IEEE 80005-2:2016 – **Utility Connections in Port. Part 2: High and Low Voltage Shore Connection systems. Data communication for monitoring and control** [2] deals with the non-safety related communication. It describes the data interfaces of shore and ships as well as step by step procedures for low and high voltage shore connection systems communication for non-emergency functions, where required. It also specifies the interface description, addresses and data type.

IEC 62933-5-2:2020 International standard: Electrical energy storage systems – Part 5-2: Safety requirements for grid-integrated ESS systems -Electrochemical-based systems [3] includes basic guidelines for safety of BESS and Requirements necessary to reduce risks: Inherently safe design of BESS considering protection from, e.g., mechanical, electrical, magnetic and electromagnetic hazards, fire, temperature and environmental hazards, chemical effects, explosions, malfunctioning of auxiliary, control and communication systems.

IEC 62933-5-1:2017 Technical specification: Electrical energy storage systems – Part 5-1: Safety considerations for grid-integrated ESS systems - General specification [4] includes basic guidelines for safety aspects of EES systems and Requirements necessary to reduce risks: EES system disconnection and shutdown taking into account, e.g., system state (grid-disconnected, stopped, shut-down), emergency shutdown and cyber security aspects.

IEC 62933-2-1:2017 International standard: Electrical energy storage systems - Part2-1: Unit parameters and testing methods - General specification [5] concerns testing methods and procedures: System implementation test on, e.g., visual inspection, continuity and validity of conductors, earthing, insulation, protective and switching devices, grid connection compatibility and EMC immunity.

IEC 62281:2019 International standard: Safety of primary and secondary lithium cells and batteries during transport [6] includes requirements for safety, Test methods and requirements and Information for safety: Evaluation of test criteria for, e.g., shifting, distortion, short-circuit, excessive temperature rise, leakage venting, fire, rupture and explosion, applicable to air, sea and land transport.

Complementary Regulations

IEC 62613-1:2019 – Plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC-Systems) - Part 1: General requirements [7]**.**

IEC 62613-2:2018 - Socket outlets and ship plugs for high-voltage shore connection systems (HVSC systems). Part 2: Requirements for dimensional compliance and interchangeability of products intended for use by different types of ships [8] specifies requirements that allow compliant ships to connect to compliant high voltage power systems through a compatible shore-to-ship connection.

IEC 60092-101:2018 – Electrical installations in ships. Part 101: Definitions and general requirements [9]**.**

EU Directive 2014/94/EU, on the deployment of alternative fuels infrastructure [10]**.**
«In its Communication entitled "Europe 2020: A strategy for smart, sustainable and inclusive growth", the Commission aims at enhancing competitiveness and energy security by a more efficient use of resources and energy. ». Electricity supply can be seen as an "alternative fuel" as it serves as a substitute for fossil oil sources and has the potential to contribute to its decarbonization, enhancing the environmental performance of the transport sector. Moreover, "shore-side electricity supply" has to be provided through a standardized interface to seagoing ships, encouraging authorities to comply with international standards.

EU recommendation 2006/339/EC, on the promotion of shore-side electricity [11]**.**
« (…) a European Union strategy to reduce atmospheric emissions from seagoing ships, which urged port authorities to require, incentivize or facilitate ships' use of land-based electricity while in port. » . This recommendation encourages the most those ports where air quality limit values rate above the average but also those where high levels of noise cause discomfort in the surrounding neighborhood.

Council Implementing Decisions on authorizing Member States to apply a reduced rate of taxation on electricity provided to vessels at berth in a port [12].
The European Commission helps thus to promote shore-to-ship supply systems. Countries such as Denmark, Sweden or Spain have already been authorized to this day.

4.2.2 Network and Connection Charges

The electricity supplied at the port is either managed internally by the port/lock of interest – e.g. by the port authority/internal grid owner; or at a regional level – electricity retailers (network charges), DSOs and TSOs (connection charges). The tariffs applied to the final consumer will be dependent on the supplier rates and on the countries current tariff types.

In this assessment and on a first stage, the different tariff types at a regional level were identified based on the available information retrieved from recognized European entities' public reports such ACER, CEDEC and Eurostat [13][14][15].

To understand the electricity infrastructure of the main ports the main stakeholders of the port have been identified. Later, the responsible stakeholders for electrical infrastructure are to be contacted to obtain the required information and for possibly establishing a contract.

Type of charges

The key elements from the electricity tariffs scheme here analysed include distribution tariffs and connection charges.

1) Distribution tariffs are here defined as charges paid to DSOs due to costs for developing and operating the distribution grid which are recurring every year. Distribution tariffs may be levied on network users in relation to the costs due to withdrawal from the grid (i.e. distribution tariff for withdrawal) and/or in relation to the costs due to injection (i.e. distribution tariffs for injection). There are essentially three types of tariffs that can be applied: Capacity tariffs, Volume tariffs and Multiple Component tariffs:

<u>Capacity tariff</u> – charges based on the connection capacity (kVA) or measured capacity (kW);
- Flat: a fixed charge based on connection capacity (kVA) or measured capacity (kW);
- Variable: different capacity levels with different tariff per level;
- Time of use: different tariffs in line with the available grid capacity (peak / off-peak); only applicable with a smart meter. (time varying tariff)

<u>Volume tariff</u> - per kWh or m3 consumed and can also be differentiated based on the volume level:
- Proportionate: consumers pay per kWh or m3 consumed, independent of volume level;
- Progressive: the tariff per kWh increases with an increasing consumption level;
- Degressive: the tariff per kWh decreases with an increasing consumption level;
- Time of use: different tariffs in line with the available grid capacity (peak/off-peak); a day/night tariff is possible without smart meter, whereas more complex peak and off-peak tariffs are only possible with smart meter. (time varying tariff)

<u>Multiple component tariff</u> – including both a capacity and a volume part.
- Fixed customer tariff: covering fixed costs (e.g. metering)
- Capacity tariff: covering capacity related costs
- Volume tariff: covering volume related costs

These can be either time dependent or not. 'Time-differentiated network tariffs' (or tariff time elements) means tariffs, differentiated by the time-of-use e.g. by peak/off-peak, season, month, weekdays/weekends, hour. Time differentiated tariffs include:

- Real time pricing (RTP), which serves to reflect the real-time cost of electricity: The price changes can occur on an hourly basis, every quarter-hour or even more often. Usually, the price variations are achieved through coupling with the wholesale market. RTP is typically the pricing model that adds the largest dynamicity to the final power price (smart-metering);
- Time-Of-Use (TOU), where the electricity prices are set for specific periods of time such as peak and off-peak hours;

- Dynamic Time-Of-Use (dTOU) - electricity prices and the peak and off-peak periods change regularly, which allows for a more accurate reflection of the situation in the energy market.
- Variable Peak Pricing (VPP) - a hybrid between TOU rates and RTP where specific periods of electricity price fluctuations are defined in advance. The price fluctuations that occur in the defined periods, vary depending on the energy supplier and the market conditions;
- Critical Peak Pricing (CPP) involves the raising the price of electricity substantially during periods of excessive demand or of a particularly low feed-in from renewables. The peak rate can be either defined beforehand or determined dynamically based on the market conditions [14].

2) Connection Charges are typically one-off charges covering the costs (or part of the costs) of connecting new users at either a distribution or at a transmission level. Since the reinforcement of the network due to new connections can also benefit the other grid users, part of those costs may be covered by distribution tariffs, instead of the connection charges, as there is a connection between these regulatory charges. The following connection charge categories are applied [13]:

- Super-shallow: All costs are socialized via the tariff, no costs are charged to the connecting entity;
- Shallow: grid users pay for the infrastructure connecting its installation to the distribution grid (line/cable and other necessary equipment);
- Deep: grid users pay for the shallow category plus all other reinforcements/extensions.

Industrial Users

In the following analysis industrial users are differentiated using the following terminology:

- Small Industrial user connected to a low voltage network, an annual consumption of 50 MWh and 35 kW of contractual power. (In The Netherlands this contractual power -35KW- is part of Household tariff)
- Large industrial user with an annual consumption of 24000 MWh, 7000 use hours and 4000 kW of contractual power [13].

Connection Charges for Energy Storage

According to ACER’s report, energy storage systems (ESS) will play a very important role on the integration of more renewable energy into the power system. ESS enable the combination of intermittent RES with the demand, ensuring that power supply matches demand in the network at all time.

Regulation (EU) 2019/943 establishes that “*network charges shall not discriminate either positively or negatively against energy storage*”. Since a storage facility may withdraw energy from or inject energy into the distribution network, it can be regarded as both a consumer and a producer located at the same network connection point. As such, non-discrimination would suggest that energy storage should be subject to distribution tariffs applicable to both energy withdrawals and, where applicable, energy injections.

The cumulative charges for withdrawal and injection must reflect the value of storage to the system. In this way, the distribution tariff design should be able to reflect the positive or negative impact that storage facilities might have.

Moreover, it is important to ensure that storage units are not remunerated or charged twice for a single service provided to or requested from the network [13].

4.2.3 Summary Tables of Identified Entities in the Port Region

In Figure (46) the main port entities are identified for the studied locations.

Port	Area	Port Land Owner [16]	Port Authority [16]	Port Operator [16]	Energy retailer at the port	TSO	Main regional DSO
Rotterdam	Dutch Port	Municipality of Rotterdam (approx. 70%) and the Dutch government (approx. 30%	Port of Rotterdam Authority (PoRA)	the Port of Rotterdam Authority (PoRA)	None	TenneT	Stedin
Amsterdam	Dutch Port	Port of Amsterdam	the Port of Amsterdam Authority	NV Haven Amsterdam		TenneT	Liander
Antwerp	French/Belgian port (Flanders)	Antwerp Port Authority.	Antwerp Port Authority.	Antwerp Port Authority.	The Port Authority's Electricity department	Elia	Distribution Network: Iveg (Right Bank), Eandis (Left Bank)
Constantza	Danube/Romania Port	Romanian state	NC "Maritime Ports Administration" SA Constanta	The port assets are leased out or sub-concessioned to private port operators.	The port administration	Transelectrica	ENEL Dobrogea
Galati	Danube	Romanian state	Maritime Danube Ports Administration LSCo. Galati	Maritime Danube Ports Administration LSCo. Galati		Transelectrica	Electrica Muntenia Nord
Bratislava	Danube/Slovak Port	Public Ports Slovakia	Public Ports Slovakia	Slovenská plavba a prístavy, a.s		SEPS	ZSE (west slovakia)

Figure 46: Table of Port entities.

4.2.4 Summary Table of Electricity Tariffs in the Considered Port Regions

Figure (47) summarizes the data retrieved from online publications regarding electricity pricing and infrastructure in the considered countries [14][13][17].

Port		Rotterdam	Amsterdam	Antwerp	Constantza	Galati	Bratislava
Tariff Components Network Charges for large industrial consumers [5][2]	**Capacity charge (€/kW)**	Yes (variable)	Yes (variable)	Yes	No	No	Yes
	Energy charge (€/kWh)	Yes (variable)	Yes (variable)	Yes	Yes	Yes	Yes
Components for general industrial users		multiple component tariff, capacity tariff depends on the measured	multiple component tariff, capacity tariff depends on the measured	multiple component tariff	volumetric	volumetric	
Time-elements in the tariff for withdrawl		not applied	not applied	Optional for all users. Day/night	not applied	not applied	not applied
Connection charges for industrial users transmission level		shallow	shallow	shallow	deep	deep	deep
Cost/Component Drivers		covering only administrative costs and local connection costs	covering only administrative costs and local connection costs	covering only the administrative costs and local connection costs (installations between customer and substation), without making distinctions regarding congestions around the connection point			
Type of connection charges for industrial users distribution level		shallow	shallow	deep	deep	deep	Shallow and deep
Connection charges value				12 771€ (plus VAT) for 330kVA connection [8]	13 000 € per connection (20kV)	13 000 € per connection (20kV)	
Cost/Component Drivers		actual cost, distance, annual fee	actual cost, distance, annual fee	actual cost, lump sum, €/MW, distance	actual cost, lump sum, user type, voltage	actual cost, lump sum, user type, voltage	actual cost, euro/MWh, voltage
Further description		All network users are subject to connection charges, same rules for all. The annual fee covers costs of capital and maintenance.	All network users are subject to connection charges, same rules for all. The annual fee covers costs of capital and maintenance.	Different rules apply, mostly depending on contracted power.	Consumers charged (shallow) actual costs on medium and high voltage and lump-sum on low voltage. Producers charged actual costs (deep).	Consumers charged (shallow) actual costs on medium and high voltage and lump-sum on low voltage. Producers charged actual costs (deep).	Different rules apply on low voltage and high voltage level.
Possible changes				In the next regulatory period 2021-2024, the tariff structure will change significantly from	The Romanian NRA intends to introduce a power-based component of	The Romanian NRA intends to introduce a power-based component of	

			1/1/2022. In order to facilitate the energy transition and anticipating on the roll-out of smart meters, a shift from energy-based tariffs towards power-based tariffs will	distribution tariff. It also intends to introduce power-based distribution tariffs for generators. These changes will be considered for the next regulatory period (2024-2029).	distribution tariff. It also intends to introduce power-based distribution tariffs for generators. These changes will be considered for the next regulatory period (2024-2029).	

Figure 47: Table of electricity tariff assessment for the different countries/regions of interest.

Table (48) contains the information about the current average network tariffs applied in each of the analysed regions for which there was information online [15].

Port		Rotterdam	Amsterdam	Antwerp	Constantza	Galati	Bratislava
Industrial average network tariff (euro/kWh)	**Average (no VAT) (1st half 2021) - 500 - 2000 MWh**	0.1128 [7]	0.1128 [7]	0.1218 [7]	0.0992 [7]	0.0992 [7]	0.1275 [7]
	500 to 2,000 MWh [6] (including VAT) (2020)	0.103	0.103				
	150 MWh and more [6]	0.057	0.057				

Figure 48. Table of industrial average network tariff (euro/kWh) for the different countries/regions of interest.

4.2.5 Summary Tables of Locks Electricity Infrastructure

Table (49) and table (50) summarize the information regarding the lock management on the Danube and on the Rhine locks, respectively.

Lock	Region	Country	Owner	Operator
Abwinden-Asten	south of Abwinden near Linz in Upper Austria	Austria	via donau - Österreichische Wasserstraßen-Gesellschaft mbH	VERBUND Hydro Power GmbH
Altenworth	in the municipality of Zwentendorf and Kirchberg am Wagram	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH	VERBUND Hydro Power AG
Aschach	Aschach an der Donau municipality in the district Eferding in the Austrian state of Upper Austria.	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH/VERBUND Hydro Power AG	VERBUND Hydro Power AG
Bad Abbach	Kelheim, Bavaria, Germany	Germany	WSA Regensburg	WSA Regensburg/ Power plant:Rhein-Main-Donau AG/ Uniper Kraftwerke GmbH
Freudenau	Vienna, Austria	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH/VERBUND Hydro Power AG	VERBUND Hydro Power AG
Gabcikovo	Dunajská Streda District, in the Trnava Region of southwestern Slovakia	Slovakia		Power plant owner and operator: Vodohospodárska výstavba
Geisling	Geisling, Pfatter, Bavaria, Germany	Germany	WSA Regensburg	WSA Regensburg/ Power plant: Rhein-Main-Donau AG/ Uniper Kraftwerke GmbH
Greifenstein	Stockerau in Lower Austria.	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH	VERBUND Hydro Power AG
Jochenstein	Untergriesbach, Germany	Germany/Austria	WSA Regensburg	WSA Regensburg/ Powerplant: Rhein-Main-Donau AG and the Austrian Verbund AG /Grenzkraftwerke GmbH
Kachlet	Passau, Lower Bavaria, Germany	Germany	WSA Regensburg	WSA Regensburg/ Powerplant: Uniper Kraftwerke GmbH
Melk	Wachau region in Lower Austria	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH/VERBUND Hydro Power AG	VERBUND Hydro Power GmbH
Ottensheim-Wilhering	Ottensheim, Upper Austria, Austria	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH/VERBUND Hydro Power AG	VERBUND Hydro Power GmbH
Regensburg	Eastern Bavaria	Germany	Rhein-Main-Donau AG	WSA Regensburg/Powerplant: Uniper Kraftwerke GmbH
Straubing	Lower Bavaria, southern Germany	Germany	Rhein-Main-Donau GmbH	WSA Regensburg/ Powerplant: Uniper Kraftwerke GmbH
Wallsee-Mitterkirchen	next to the Lower Austrian municipality of Wallsee in the area of the Upper Austrian market town of Mitterkirchen	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH	VERBUND Hydro Power AG
Ybbs-Persenbeug	municipality of Ybbs and Persenbeug in Lower Austria	Austria	viadonau Österreichische Wasserstrassen-Gesellschaft mbH	VERBUND Hydro Power AG
Djerdap/Portile de Fier I	Iron Gate gorge, between Romania and Serbia	Serbia/Romania		

Djerdap/Portile de Fier II		Serbia/Romania		

Figure 48: Table of locks in the Danube mapping of the owners and operators.

Lock	**Region**	**Country**	**Location**	**Owner/Operator**
Iffezheim	Iffezheim, Baden, Baden-Wuttenberg	Germany	Grand Canal d'Alsace	RKI is half owned by EnBW Kraftwerke and half by EDF
Gambsheim	Bas Rhin Department, Grand-Est Region, Alsace	France	Grand Canal d'Alsace	The locks are managed by Voies Navigables de France, and the hydro-electric installations by CERGA, a subsidiary of EDF and EnBW
Strasbourg	Bas Rhin Department, Grand-Est Region, Alsace	France	Grand Canal d'Alsace	
Gerstheim	Bas Rhin Department, Grand-Est Region, Alsace	France	Grand Canal d'Alsace	There is also an EDF hydro-electric installation incorporating a lock and a road crossing on the Rhine.
Rhinau-Sundhouse	Bas Rhin Department, Grand-Est Region, Alsace	France	diversion canal	
Marckolsheim	Bas Rhin Department, Grand-Est Region, Alsace	France	diversion canal	
Vogelgrün	Haut-Rhin department, Grand Est in north-eastern France	France	diversion canal	the EDF lock keeper manages the placing of the boats in the chambers and the opening and shutting of the gates (a free service twenty-four hours a day, all year round).
Fessenheim	Haut-Rhin department, Grand Est in north-eastern France	France	diversion canal	the Fessenheim lock has two chambers. Each year between 18 000 to 20 000 vessels use it. From the control cabin situated above, the EDF lock keeper manages the placing of the boats in the chambers and the opening and shutting of the gates. grid operator RTE
Ottmarsheim	Haut-Rhin department, Grand Est in north-eastern France	France	diversion canal	EDF UP Est
Kembs	Haut-Rhin department, Grand Est in north-eastern France	France	diversion canal	twin locks The Kembs power plant is a run-of-river power plant owned by Électricité de France on the Rhine canal in France .

Figure 49: Table of locks on the Rhine mapping of the owners and operators.

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4.2.7 Future Assessment

This study serves as the first phase of the electrical infrastructure study. More concrete answers are expected through contact with the different stakeholders identified in the most relevant locations. The final objective is to understand the charges applied and constraints for the implementation of the CD solution on the electrical level. Once the electrical infrastructure and tariffs applied are known, this information can be exploited to the EaaS platform to later be used once CD solution is operational on a commercial level. This is expected to be achieved mainly from the output of a questionnaire sent to stakeholders. For the sake of the demonstration to be carried on the scope of the project, the priority is to have this information about the port of Amsterdam.

The questionnaire (see Appendix A) was sent for the port authorities for six different port locations to obtain a set of information including the answer to the following:

- Who is the energy retailer at the Port?
- Is the port's internal grid managed by one entity? If yes, do the port's consumers have a specific contract with the retailer or it is all managed by the internal grid owner?
- Can the electricity be sourced from power plants at the port or there is a direct grid connection?
- Do industrial consumers (within the port) pay a multi-component tariff that includes both Capacity and Volume of energy? And what type of tariff is applied to the volume part (time-of-use, real-time energy price)?
- Are there any special tariff conditions for battery charging applications?

On a later stage, the same will be done for the other mentioned ports and locks in chapter 2.

4.3. Recent Developments

According to *Power Technology Research*, European ports are very active in the commitment to reduce the environmental impact related to the maritime sector. In the last decade Europe has been in the forefront of the deployment of Onshore Power Supply (OPS) at major ports. In fact, more than 80% of all shore power facilities installed worldwide are located in Europe. As indicated in Figure 50, most of these facilities are low voltage, operating at voltage levels ranging from 400 V to 690 V and are used by container ships, Roll-on/Roll-off (Ro-Ro) vessels, and ferries. High voltage facilities, which operate at voltage levels ranging from 6600 V to 11000 V are mostly used by cruise ships and are mostly installed at cruise ports.

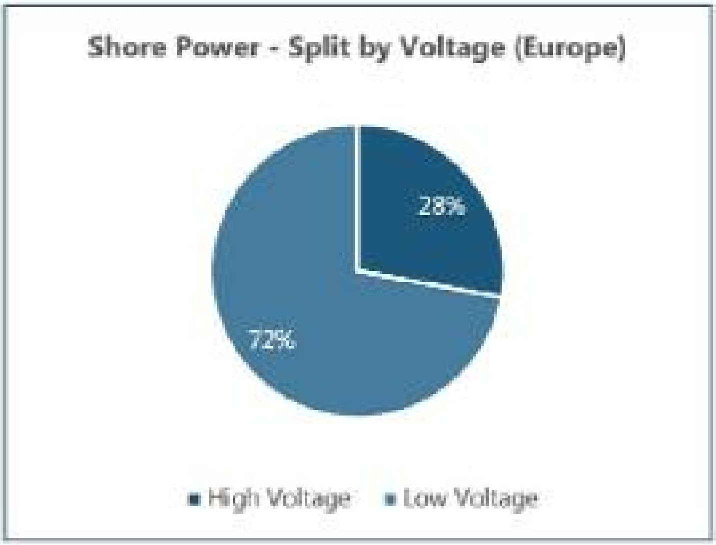

Figure 50: Shore power split by voltage in Europe. / Power Technology Research.

Battery electric propulsion – Danube Transnational Programme

According to the fact sheet report from the Danube Transnational Programme and given the fact that most of the shore power connections are low voltage, the existing port infrastructure is usually too weak for loading large batteries. The operators of the electrical power grids at the quay edge would have to provide connected loads in the megawatt range. In the background, the energy must be provided in the entire electrical network by power plants [16].

The following information was retrieved from articles and the most recent news from the studied ports and maritime related information platforms.

Port of Rotterdam

24-08-2021 Onshore Power Supply Gaining Popularity in European Ports
'Recently, the Port of Rotterdam opened its new shore power plant at Calandkanaal terminal which will supply offshore crane vessels with onshore power from the wind.

Bakker Sliedrecht will provide the electrification solution for Heerema's Thialf and Sleipnir crane vessels that will enable their shoreside operation to be powered by renewable electricity. Since August, the project consortium (composed by Heerema, Rotterdam Port Authority and Eneco) has been building electrical infrastructure, called an "e-house" on the quay near the Calandkanaal in Rotterdam where the Heerema vessels are docked, that can supply 20MW of clean power. Bakker Sliedrecht will supply the required transformers, shore connection switchboards and interface to the existing power distribution system and will also install low and high voltage cables, to convert voltages from 11kV to 4.16kV'.

Technical specifications:
Capacity: 20MW, Frequency: 50 and 60Hz

'There are plans based on a feasibility study conducted by Rotterdam Shore Power BV to build another power plant at Vopak Europoort terminal by the end of this year. The Netherlands is supporting deployment of shore power facilities at ports by reducing the applicable tax rate for ships using shore-side electricity and also by reducing the energy tax rate for shore-side power plants. The government is providing funds through the Ministry of Finance and the European Green Deal with plans to install more shore power facilities by 2030'.

5-01-2021 Park-Line Aqua supplies shore-based power system inland ports
'Park-Line Aqua (formerly part of the Parkmobile Group) is a user, service and payment platform for the maritime and logistic sector. The services are focused on digitization and sustainability improvement so as to create a uniform platform (market-place) with only a single all-inclusive invoice per month. The services are currently operational in more than 50 ports/municipalities in the Netherlands and Belgium and range from shore-based power to collecting port dues'.

15-10-2020 Dutch Port of Rotterdam and the Municipality of Rotterdam are working together on the joint rollout of shore-based power for sea-going vessels in Rotterdam.
'In the years ahead, the aim is to realize eight to ten concrete shore-based projects, which will be divided between the programme's three main pillars'.

'This programme is expected to require a total investment of some €125 million (about $147 million). The majority of this budget will be contributed by the companies involved, the municipality and the port authority. Another €50 million will need to be covered by public funding'.

16-12-2019 Shore power trial for coasters in Rotterdam - Mobile power stations
'Over the coming five months, shore power systems will be tested from the following five companies:

- ENGIE Ventures & Integrated Solutions B.V.: Hybrid system with a Big Battery Box, integrated with a motor generator on biofuel (HVO);
- PON Power & sister companies: Hybrid container with a battery combined with a generator on HVO fuel and a 20ft container with solar panels on the roof;
- Aggreko Benelux: LNG-powered Gas engine in a 20ft container;
- Mobiele Stroom BV: Bio LNG-powered turbine in a 20ft container;
- JP-Energiesystemen B.V: Hydrogen fuel cell generator combined with a small battery.

The trial will also test different energy sources, such as hydrogen, battery, bio LNG, LNG and hybrid solutions. The latter solution combines various energy sources. For the above-mentioned fuels, an on-site generator is needed to convert these into electricity'.

10-10-2019 Port of Rotterdam's power grid can be reinforced more efficiently and at a lower cost

‘The joint study concludes that this issue is particularly urgent because the capacity of the existing power grids and connections in the port of Rotterdam does not suffice to accommodate future plans for a sustainable port area. The lead time for realizing new high voltage substations and power lines can be anything from 3 to 10 years […] The connecting theme in the plans to reinforce the grid is the increased transport at higher voltage levels (150 kV and higher) combined with smaller service regions at lower grid levels (66 kV and below). One promising alternative for the power grid is dividing the 150 kV network into a western, central and eastern section. Creating a larger number of substations within the distribution network will ultimately result in fewer power lines in the pipeline corridors and shorter connecting lines to the clients’ respective locations […] At present, new client applications for extra connection capacity are handled independently of each other and on a ‘first come, first served’ basis. This is a result of the principle laid down in current regulations that grid operators’ procedures need to be non-discriminatory. In many cases, the result is that new and existing clients are hooked up to the public grid via long connecting lines and are confronted with substantial connection costs’.

'Internet of Things'-platform

‘Under the direction of the Port of Rotterdam Authority, IT partners IBM, Cisco, Esri and Axians have been working together to provide an Internet of Things (IoT) platform. The Port Authority uses this cloud platform to collect and process data from sensors located throughout the port. In this way, real-time information about infrastructure, water and air comes in, enabling the port of Rotterdam to improve its services. The ultimate aim is to create a so-called ‘digital twin’ of the port in 4D, i.e. a digital representation of the actual, physical port’.

2015 - Euromax electrical system design
‘Owned jointly by the European container Terminals and Maersk, developed a 132-hectare terminal in the western part of the Rotterdam Port. GTI engineering design the shore power electrical infrastructure.’

Technical specifications:
EU Grid - 380 kV /50 Hz
Regional Grid - 150 kV /50 Hz
Euromax 25 kV /50 Hz
Power Station - 40 MVA/25 kV/50Hz

Port of Amsterdam

Port of Amsterdam plans to increase the medium voltage grid.
‘Port of Amsterdam reserves space for and invests in infrastructure and partnerships with customers, start-ups and partners. We do this in order to continue to be a sustainable international energy hub in the future. This is done along three pillars:

- scaling up sustainable energy production and storage;
- attracting and facilitating the production of renewable fuels and circular raw materials;
- developing the infrastructure necessary for the sustainable transition’.

Related to scaling up sustainable energy production and storage is:

- Project Clean Amsterdam
- Increased medium-voltage grid
- Shared Energy Platform (SEP)

07-05-2021 Port of Amsterdam installs new smart shore power cabinets

‘In the coming months Port of Amsterdam will replace all existing shore power units with smart, green shore power. This will happen to all cabinets in the port area within the ring (A10) of Amsterdam. The new shore power cabinets are a lot smarter and easier to use than their predecessors. For example, you can operate them using a Park-line app, in which you indicate how much power you need’.

11-02-2021 Shore power for short sea vessels in the port of Amsterdam
‘On 8 and 9 February, the first test took place with shore power for short sea vessels at a terminal. Shipping company Wilson moored their ship Wilson Goole at VCK Logistics' Waterland Terminal. The ship received power via SKOON's battery. The battery test is another step towards a more sustainable shipping industry. The battery can supply green energy anywhere in Amsterdam and is then filled with local wind energy from Windpark Ruigoord or with energy from biomass from AEB. With this, it is capable of supplying 630 kWh of electricity. This equates to at least twelve hours of shore power. Or two months for a two-person household’.

‘This has recently been done in cooperation with the Shared Energy Platform (SEP). SEP is an initiative of the Port of Amsterdam to increase the available capacity in the electricity grid’.

Port of Antwerp

16-10-2020 Belgian and Dutch inland ports plan to establish a single shore-based power system
‘On behalf of all these ‘Walstroompartijen’ (Shore-based Power Parties), the Port of Rotterdam Authority has published a European call for bids, which will ultimately lead to the selection of a contractor for these services. —> Park Line Aqua won the European tender.’

Port of Constantza

Port Energy Branch Tariffs can be publicly consulted for the port of Constatza through the following link: https://www.portofconstantza.com/pn/page/np_tarife/tarif_34_en.html

5. PHASE 4 – ASSESSMENT OF CURRENT DIRECT INFRASTRUCTURE REQUIREMENTS

5.1. Literature review of modelling transport electrification

The aim of this chapter is to provide a review of the models developed to tackle the main logistic challenges that electrifying the transport have and to conclude on the applicability of these models to the particular case of IWW shipping electrification.

Given the fact that, as far as this research concerns, there is no specific literature on optimisation models for IWW shipping electrification, a literature review on other modes of transport was performed. Then a comparison with IWW was made to determine the applicability and limitations of existing models to IWW shipping. In particular, buses were chosen as the mode of transport to compare. The reasons for this are the availability of literature and the similarity of bus road transport and IWW transport in terms of type of vehicles and operations. Buses are large vehicles with higher power demands if compared to cars and have fixed routes and schedules, like IWW vessels. Trucks could have been another option to compare, as they are also large vehicles with relatively high demands of power, long routes and less stops than buses, similarly to IWW vessels. However, literature on trucks electrification is also limited.

To perform this literature review Scopus and Science Direct were used to find suitable papers. The terms ‘buses’, ‘electrification’, ‘challenges’ and ‘model’ were used in different combinations.

Moreover, backward snowballing was used to expand the number of papers considered in this literature review.

The results of the literature review are structured starting with the challenges that electrifying buses transport have and how these can also apply to IWW transport. Followed by a description of the models developed to address these challenges for buses, discussing the possible applicability and limitations if implemented for IWW vessels. Finally, conclusions are made on the need to develop a specific model for IWW shipping to analyse the possibility of electrification with exchangeable batteries.

5.2. Logistic challenges of transport electrification

As mentioned before, in this subchapter, the logistic challenges that electrifying buses have will be described. At the end of this section a parallelism of these challenges to IWW vessels will be done.

In the implementation of any innovation there are always challenges to overcome. In the case of buses electrification these can be of many types, such as users' reluctance to change and high implementation costs. The reliability of the system becomes a key aspect to successfully implement buses electrification. For this, a proper combination of charging infrastructure and batteries that provides a reliable energy supply to maintain a stable operation, even under demanding conditions, is needed. As study by many authors, securing system reliability leads to logistic challenges to overcome.

The first challenge, regards the number and location of the charging infrastructure. The strategic location of charging stations is key for the system to properly work and for users to trust it. The charging infrastructure will be in place in the network for many years. Therefore, the location decisions will also affect tactical and operational decision for these charging stations. Moreover, the large capital costs involved in installing charging infrastructure, make the decision on number and locations of charging stations not straight-forward.

Apart from the location problem, decisions need to be made on the charging stations capacities and charging regimes. The size or capacity of the recharging stations affects the transportation planning as stations cannot serve more than their installed capacity. Electric buses have higher power demands than electric cars, and they operate under fixed routes and daily schedules, therefore subject to more constraints in relation to where the charging infrastructure can be placed. Moreover, a charging station can be fast or slow charging. Standard charging is performed with a moderate charging power mainly in the bus depot overnight and during longer brakes. Charging schedules can be implemented in buses electrification, for example use overnight charging to avoid the need of fast charging stations. However, this causes a high battery capacity and a high weight of the system, when the bus shall be operated the entire day. Fast charging on the track during operation can reduce the battery capacity and therefore the weight significantly. However, there is a trade-off between charging speed/time and the damage to the battery, making this type of charging to have their own limitations. To overcome this, battery exchange schemes/stations can be implemented. This avoids the bus to be idle while recharging as well as battery deterioration, as battery life can be extended by charging at slower speed. Some drawbacks of battery swap stations include the need of unified battery standards among vehicles and stations. Decisions on the station type will directly affect the charging times and will depend on the buses power demand, size of batteries, the location of the stations, but also on the buses schedules to see if their provide sufficient charging times at certain locations. As it can be seen the charging station design (size, power and type) and location decisions are interrelated, making it not trivial to decide upon the best option.

The second main challenge of bus electrification regards the limited driving-range capabilities of the vehicles which are restricted by the amount of electricity stored in their batteries. This challenge has been address by several authors, as it is a key barrier that reduces the attractiveness of bus electrification and imposes non-trivial additional constraints when designing efficient distribution routes. Maximum battery capacity is linked to technological limitations, but also to size, weight and cost limitations.

Batteries can make up to one-third of the total cost of an electric bus. Therefore, a balance between battery capacity and range needs to be made. The restriction in driving range imposed by the batteries to the buses, has also an impact on buses schedules, as additional times and stops might be required to charge the batteries. Again this problem is linked to the charging infrastructure location problem.

When thinking of the possible challenges that the electrification of IWW vessels can have, a parallelism can be drawn with some of the abovementioned challenges of buses electrification. For example, the charging infrastructure location, number and design (size and power) will also be an issue with IWW vessels. Charging stations, as in the case of buses, need to be in the route of the vessels, because their routes are fixed. Detouring a vessel to go to a charging station outside its route is not economically feasible. The problem for IWW vessels will have the added constraint that charging stations need to be at the terminals at which the vessels stop, near the cranes for the loading and unloading of the batteries and need to have access to power grid and ensure land availability. The challenge concerning the charging time will also be present in IWW vessels. In an optimal operation the vessel should not have to be idle at a terminal longer than if sailing with diesel fuel. Therefore, the system needs to provide either fast charging infrastructure to built-in batteries or available charged batteries to swap if an exchangeable battery system is implemented. The possibility of overnight charging seems quite infeasible as shipping is usually a 24/7 operation. Moreover, the challenge of battery range will also be present in IWW vessel electrification. The power requirement of a vessel is huge in comparison with a bus, making the need of either very large built-in batteries or sufficient swapping stations on the route a must for the system to work. Additional vessels stops and extra times for charging or swapping batteries need to be minimised.

5.3. Models developed to overcome the logistic challenges of transport electrification

In this subsection a selection of models developed to overcome the abovementioned logistic challenges that can be found in literature for buses electrification will be reviewed. In the following subsection the applicability of these models to IWW vessels will be addressed.

When looking into the researched models to address the logistic challenges for electrifying buses, it is usual to find authors addressing more than one logistic challenge combined. In particular battery range restrictions are usually used as a constraint to the problem.

Starting with the number and location of charging infrastructure challenge, the research performed addresses this problem and proposes a mixed-integer problem decomposed in two subproblems. The first one aims to solve the uncapacitated fixed charge facility location to find the optimal station location and the demand of each station. Where as the second one, aims at finding the optimal configuration of the localised charging system, in particular the charger type and battery inventory. The problem is solved for a fleet of battery electric buses and aims at minimising the total investments, by determining the needed number of swapping stations and their locations and the demand assigned to each of them. The buses go to the swapping station from the depot, meaning they do not need a swapping service on during the route. The main limitations of the model are that it is assumed that a battery will be available at a station when a bus arrives, busses will only reach swapping stations from depot, meaning they can finish their whole route without recharging their batteries and swapping stations are assumed uncapacitated, meaning there is no limit of batteries the stations can charge and no charging time. Moreover, the model solves the location of the stations and the demand assigned to each station first, and then determines the number of needed batteries. Therefore, the interrelation between stations number and location and the needed batteries is not modelled.

In this same line of research, the optimal distribution of charging infrastructure for electric buses was studied. The model they developed is a mixed-integer linear programming (MILP) that aims to assess upscaling the implementation of electric buses by identifying the optimal spatial distribution of charging infrastructure to minimise costs and energy consumption. The model is based on balancing the energy at arrival of a stop as the energy the bus had when leaving the previous stop minus the required energy to travel the distance between stops. The main limitation of the model regards to the location of the charging stations being limited to starting and end stops in the buses routes, meaning that the battery capacity should be enough to do the whole trip.

Another research which looks to the interaction of an efficient layout of the charging infrastructure and an appropriate dimensioning of battery capacity was examined. The authors propose an advanced mixed-integer linear optimisation model that solves a capacitated set covering problem to determine the number and location of charging stations and the required battery capacity for each bus line, minimising costs and without altering the original operational schedule. Some key aspects of the model proposed in this research are the network perspective which allows to identify synergies when the charging infrastructure is shared by several bus lines at once, the incorporation of the trade-off between battery capacity and charging infrastructure and the nodal energy balance. One limit that this model has is that the charging time is limited to the time the bus it at the stop.

To tackle the battery charging times challenge for buses electrification, research has focused on vehicle schedules and battery reservation strategies to properly match the power demand from the vehicles with the available resources (batteries). Research in this direction was added, in which the authors find the optimal location of the EV charging among the swapping stations available in the network. This is done by scheduling the arrival of the buses at the swapping stations, and by determining the charging priority of the depleted batteries at the stations. The scheduling allows to guarantee that a fully charged battery will be available and ready to deploy when the vehicle arrives at the station. Therefore, there is no waiting time of the bus for charging. The authors developed a time-discrete multi-objective optimisation algorithm to solve the problem.

5.4. Conclusions and reflections of the application of existing models to electrify the IWW shipping with exchangeable batteries

As it was mentioned before, as far as this research concerns, the application of exchangeable batteries to power vessels has not been in depth researched before. Many questions need to be answered for such a concept to be fully implemented on a large scale. Some of which regard the logistics challenges of the exchangeable batteries and the charging stations. Despite some parallelisms can be drawn from studied problems on buses electrification and the developed models to solve them, there are some peculiarities of the implementation of this concept in inland waterways vessels which make the direct applicability of these models not possible.

For example, the extremely high costs of the needed batteries and charging stations for IWW vessels make their optimisation a key aspect for the exchangeable battery concept to be economically feasible and, hence, successful. Therefore, the interrelation between both need to be considered when finding their optimal number and location.

Moreover, assuming a fully-charged battery is available at all times to be loaded on a vessel is not realistic, as the needed charging times at the charging stations are not being considered. Charging stations also have a limit amount of charging spots and, therefore, a limited charging capacity. This is why the time needed to charge batteries needs to be considered, in order not to overload the stations with batteries that cannot be charged. Apart from this, it is not realistic to limit the charging time, as the batteries needed to power IWW vessels are very large, and the charging times are not neglectable. Battery level is a key parameter that should be tracked so as to optimise the charging times and number of needed batteries.

Allowing the possible vessels to use exchangeable batteries only to those which power requirements are low enough to be fulfilled with the power of batteries on board is a major limitation. The combination of charging stations locations and batteries in the network should allow the fleet of vessels analysed to sail electric regardless of the power requirement. If needed more charging stations should be placed in the system to swap the depleted batteries for fully charged ones. Therefore, all vessels stops at terminals should be considered as a potential charging station to allow possible batteries swapping in the route and not only on end terminals. Finally, vessels' routes and schedules are fixed making it not realistic for vessels to choose the charging station at where to load/ unload the batteries according to the possible queue or battery charging schedules.

Despite the abovementioned limitations for the applicability of the assessed models to IWW vessels, there are some concepts developed by the authors that can be applied in the development of a new model for IWW shipping. In particular the cost minimisation perspective, for the optimisation of the exchangeable battery system is of interest for this research. Apart from this, the time-discrete modelling approach is of relevance for this research. Developing a model with discrete time-steps to represent the power requirements of vessels, their locations and the battery charge level seems reasonable. Moreover, the nodal energy balance concept has potential applicability. The battery charge level needs to be determined at all times, therefore, a energy balance between time steps is needed. Finally, the network perspective to develop a MILP as done is also of relevance for this research. Finding possible synergies between the charging infrastructure, the needed batteries and the vessels will lead to better results in terms of DS and batteries optimisation.

In this research, the problem aimed at solving, requires to incorporate not only the swapping stations or charging stations optimisation but also the battery optimisation. For which battery location and battery charge level are two parameters that need be tracked at all times. Therefore, this research aims to extend the existing literature and propose an optimisation model for the implementation of exchangeable batteries in IWW shipping in order to minimise costs, by optimising the needed number and locations of charging stations and the number of batteries, so as to satisfy a given demand of vessels, with their specific routes and power requirements. For this, the following concepts of the assessed models will be used: energy balance, synergies possibilities by using a network perspective of the system allowing batteries to be shared by vessels sailing in different routes, time-discrete modelling and cost minimisation approach.

5.5. Method to analyse the exchangeable batteries distribution and charging stations location for IWW shipping

In this chapter the method used to analyse the implementation of an exchangeable batteries system to IWW ship- ping is explained. Starting by the description of the conceptual model that sates the model objectives, project requirements, inputs and outputs and the assumptions and simplifications made. Followed by a subchapter with the description of the optimisation model developed to assess the abovementioned system implementation. In this subchapter the modelling concepts, the mathematical formulation, the model verification and validation are explained.

5.6. Conceptual model for the implementation of exchangeable batteries and charging stations to power IWW vessels

A conceptual model is a specific description of the computational model that is been developed. The components of the conceptual model described in this chapter are the model objective, the project requirements, the model inputs and outputs, the assumptions and the simplifications made.

In the figures (51), (52) below, a general overview of the model with the inputs and outputs is shown.

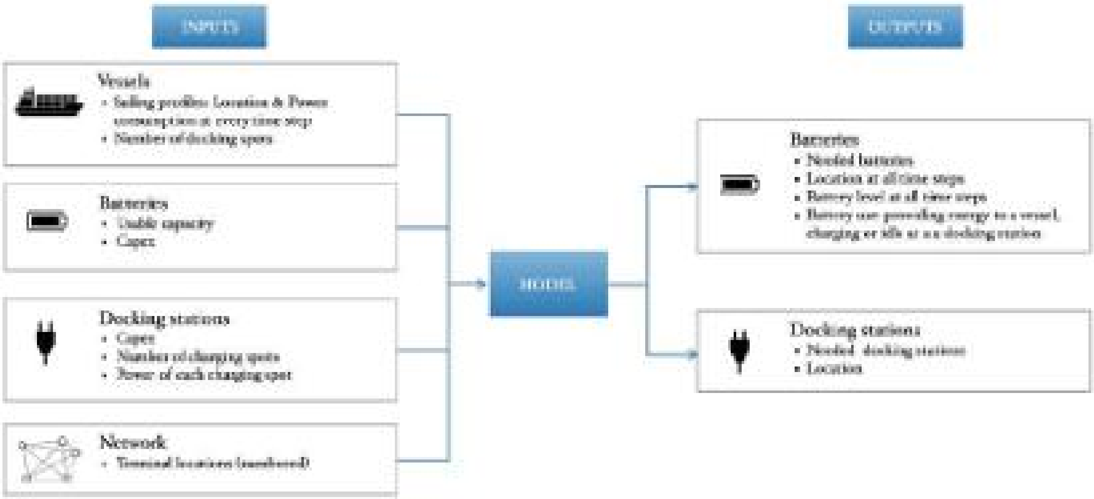

Figure 51: Model overview. / Optimal exchangeable battery distribution & docking station location for electric sailing in IWW shipping (Mariana Pina Rodriguez, 2021).

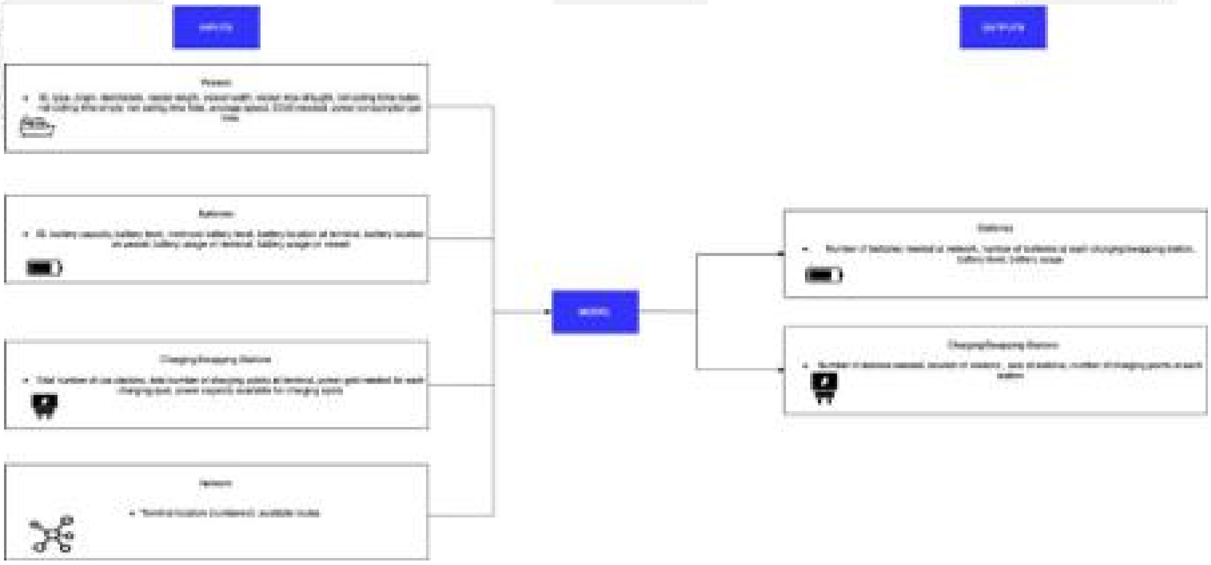

Figure 52: New Model overview.

5.6.1 Model Objectives

The model objective is to find the optimal combination of batteries and charging stations to successfully pro- vide the required power to all vessels, minimising batteries and DS investment costs, in order to implement exchangeable batteries to IWW shipping. To do so several scenarios are analysed varying: battery capacity, charging spots on vessels and charging station power and charging stations spots.

5.6.2 Project requirements

- **Time scale**: The duration modelled needs to account for the longest round trip of the fleet of vessels considered.
- **Flexibility**: The model should allow to analyse different fleet composition (vessels with different routes and power consumption), different corridors and terminal locations.
- **Scalability**: The model should allow easy scalability to more terminals, more vessels and potentially more time steps.

- **Scenario analysis**: The model needs to easily allow to analyse different input scenarios such as different battery capacity, charging spots at charging station and their power, and charging spots in vessels. Moreover, the model should allow to analyse DS locations at specific terminals. Therefore, the DS locations need to be able to be fixed.

5.6.3 Model Assumptions

Batteries

- Fleet composition: All batteries are assumed to be lithium-ion. Therefore, no heterogeneous battery technologies is considered, for example a mix of hydrogen cells and lithium-ion batteries.
- Battery ageing and power losses: given the added complexity that modelling battery ageing will give to the problem, and the fact that only a short period of time will be modelled, it was decided not to include ageing directly. All the power losses and power variability due to use or temperature, as well as ageing, are included in the maximum usable battery capacity. Each battery is modelled individually so different scenarios with different capacities can be modelled to account for different battery ageing and charging regimes.
- A minimum battery level is set to avoid batteries to fully discharge and to keep a safety margin to account for unforeseen events that might require larger power consumption from the vessel, than those stated in the sailing profiles.

Charging stations

- It is assumed that the locations of the possible charging stations can guarantee space and availability of connection to the electric grid.

Vessels

- The sailing profiles (routes and power consumption) used for the study case are those given by the vessels owners for an average day sailing on diesel fuel.
- Vessel speeds and distances are not modelled. These can indirectly be accounted for by altering the energy consumption per time period of the sailing profiles (model input).

Others

- The only costs considered in the model are those for the batteries and charging stations Capex. In other words, no operational costs are considered.
- The costs for vessels' retrofit and shippers revenue losses for having fewer containers on board to accommodate the batteries are not considered.
- A service level of 100% is considered, meaning all the vessels' power demands need to be satisfied. The model looks for the needed batteries and charging stations so that the whole fleet sails electric.

5.6.4 Model Simplifications

- Running time is a huge limitation to the model, the selected time scale and time steps need to allow to obtain results within reasonable time yet relevant to make conclusions. Therefore, the maximum number of vessels model is limited to four and the vessels' sailing profiles are simplified so as to describe the vessels' routes and power requirements in a maximum of 24 time steps.
- The batteries are linearly charged/ discharged in time.
- The batteries supply energy to the vessel alternatively in each time step. Meaning, that if more than one battery is on a vessel, at a time step p only one battery is used to power the vessel.

- Battery age and size heterogeneity, as well as, energy losses and battery degradation, are indirectly represented by different maximum battery capacity.
- Vessels' sailing profiles (sailing times and power consumption) are not changed due to external factors like sailing speed, the weather or currents.

5.7. Optimisation model development for the implementation of exchangeable batteries and charging stations to power IWW vessels

In this chapter the optimisation model developed in this research is explained. Starting by a general explanation of the model and the modelling concepts used, followed by the mathematical formulation of the model and its verification and validation.

5.7.1 Model Description & Modelling Concepts

The problem that is aimed to solve in this research requires to develop an optimisation model for the exchange- able battery fleet and charging stations locations. As explained in previous sections, is not possible to have a large fleet of batteries available for vessels at all times. The problem needs to be modelled from the battery perspective, as it needs to keep track of the batteries location and battery charge level in order to match them with the fixed sailing routes of the vessels.

As the demand of vessels, including the sailing routes and the power requirements, as well as, the terminal locations are precisely known, the model is optimised as deterministic. Moreover, given the nature of the problem to model, discrete time representation comes as a straightforward representation of it. The vessels' locations and power requirements, as well as, the batteries locations and battery charge levels can be easily represented in hourly time steps. This makes it also easier to understand the outputs, as well as, to modify the input values, which can be useful for the company later on.

Given the project requirements from the conceptual model, the developed model needs to be flexible and scalable. Therefore, it was decided to simplify the network and represent the terminals with numbers. Then the sailing profiles of the vessels are adjusted so as to show in each time step their location (at a terminal or sailing). In this way no specific node-arc representation is needed, allowing for the model to be adapted and or extended to any other network.

In this research a mixed integer linear programming (MILP) model with discrete time is proposed to find the optimal number of batteries and charging station number and locations to make the vessels demand be effectively powered by electric energy. Formulating problems as MILP has the advantage that optimal solutions can be found. As all the equations that represent the problem of this research (objective function and constraints) can be formulated in linear equations, this is the chosen method, which is solved by using the commercial solver Gurobi.

5.7.2 Mathematical formulation

Sets

$b \in B$ {1,2,3,. . . S}	Set of batteries
$v \in V$ {1,2,3,. . . ,M}	Set of vessels
$t \in T$ {1,2,3. . . T}	Set of terminals
$p \in P$ {1,2,3,. . . H}	Set of time periods

Variables

$$n_b = \begin{cases} 1, if\ battery\ b\ is\ being\ used \\ 0, \qquad\qquad otherwise \end{cases},$$

$$u_t = \begin{cases} 1, if\ terminal\ t\ is\ used\ as\ docking\ station \\ 0, \qquad\qquad otherwise \end{cases},$$

$$x_{b,t,p} = \begin{cases} 1, if\ battery\ b\ is\ at\ terminal\ t\ at\ time\ p \\ 0, \qquad\qquad otherwise \end{cases},$$

$$y_{b,v,p} = \begin{cases} 1, if\ battery\ b\ is\ on\ vessel\ v\ at\ time\ p \\ 0, \qquad\qquad otherwise \end{cases},$$

$$k_{b,t,p} = \begin{cases} 1, if\ battery\ b\ is\ being\ charged\ at\ terminal\ t\ at\ time\ p \\ 0, \qquad\qquad otherwise \end{cases},$$

$$m_{b,v,p} = \begin{cases} 1, if\ battery\ b\ is\ providing\ energy\ to\ vessel\ v\ at\ time\ p \\ 0, \qquad\qquad otherwise \end{cases},$$

$l_{b,p}$ Battery level of battery b at time p

Parameters

Terminals

$chp_{t.}$ Number of charging points of a DS installed at terminal t

$pw_{t.}$ Power of each charging spot [kW]

Batteries

$cap_{b.}$ Maximum battery capacity of battery b [kWh]

mlv Minimum battery level charge required to be used in vessel

mlb Minimum battery level at all times to avoid batteries to be fully discharged (safety margin)

Vessels

$sp_{v,t,p}$ Sailing route. If vessel v is at terminal t at time step p, then $sp_{v,t,p}$ =1 and 0 otherwise.

$pv_{v,p}$. Power consumption of vessel v at time step p [kWh]

chv_v. Number of batteries that can be fitted in vessel v (charging spots)

Initial values

$Lb_{b,0}$ Battery level of battery b at start of period (p=0)

$$Ut_{b,t,0} = \begin{cases} 1, if\ battery\ b\ is\ at\ terminal\ t\ at\ p = 0 \\ 0, \qquad otherwise \end{cases},$$

$$Uv_{b,v,0} = \begin{cases} 1, if\ battery\ b\ is\ on\ vessel\ v\ at\ p = 0 \\ 0, \qquad otherwise \end{cases},$$

$$k0_{b,t,0} = \begin{cases} 1, if\ battery\ b\ is\ at\ terminal\ t\ and\ is\ being\ charged\ at\ p = 0 \\ 0, \qquad otherwise \end{cases},$$

$$m0_{b,v,0} = \begin{cases} 1, if\ battery\ b\ is\ on\ vessel\ v\ and\ the\ battery\ is\ being\ used\ at\ p = 0 \\ 0, \qquad otherwise \end{cases},$$

Others

M_1 Large number

M_2. Small number

Constraints

$$n_b . M1 \geq \sum_{t \in T} \sum_{p \in P/\, p>0} x_{b,t,p} + \sum_{v \in V} \sum_{p \in P/\, p>0} y_{b,v,p}\ ;\ \ \forall b \in B \tag{2}$$

$$u_t . M1 \geq \sum_{b \in B} \sum_{p \in P/\, p>0} x_{b,t,p} . n_b\ ; \quad \forall t \in T \tag{3}$$

$$1 \geq \sum_{b \in B} m_{b,v,p} \geq pv_{v,p} . M2\ ;\ \forall v \in V\ ;\ \forall p \in P\ ;\ \forall p > 0 \tag{4}$$

$$l_{b,p} \leq l_{b,p-1} + \left(\sum_{t \in T} pw_t . k_{b,t,p} - \sum_{v \in V} pv_{v,p} . m_{b,v,p} \right)\ ;\ \forall b \in B\ ;\ \forall p \in P\ ;\ \forall p > 0 \tag{5}$$

$$\sum_{t\in T} x_{b,t,p} + \sum_{v\in V} y_{b,v,p} = n_b \; ; \; \forall b \in B \; ; \; \forall p \in P \; ; \; \forall p > 0 \quad (6)$$

$$x_{b,t,p} \leq x_{b,t,p-1} + \sum_{v\in V} \left(y_{b,v,p-1} . sp_{v,t,p}\right) \; ; \; \forall b \in B \; ; \; \forall t \in T \; ; \; \forall p \in P \; ; \; \forall p > 0 \quad (7)$$

$$y_{b,v,p} \leq y_{b,v,p-1} + \sum_{t\in T} \left(x_{b,t,p-1} . sp_{v,t,p}\right) ; \; \forall b \in B \; ; \; \forall v \in V \; ; \; \forall p \in P \; ; \; \forall p > 0 \quad (8)$$

$$\sum_{b\in B} x_{b,t,p} \leq cht_t \; ; \; \forall t \in T \; ; \; \forall p \in P \quad (9)$$

$$\sum_{b\in B} y_{b,v,p} \leq chv_v \; ; \; \forall v \in V \; ; \; \forall p \in P \quad (10)$$

$$k_{b,t,p} \leq x_{b,t,p} \; ; \; \forall b \in B \; ; \; \forall t \in T \; ; \; \forall p \in P \; ; \; \forall p > 0 \quad (11)$$

$$m_{b,v,p} \leq y_{b,v,p} \; ; \; \forall b \in B \; ; \; \forall v \in V \; ; \; \forall p \in P \; ; \; \forall p > 0 \quad (12)$$

$$x_{b,t,0} = Ut_{b,t,o} . n_b \; ; \; \forall b \in B \; ; \; \forall t \in T \quad (13)$$

$$y_{b,v,0} = Uv_{b,v,o} . n_b \; ; \; \forall b \in B \; ; \; \forall v \in V \quad (14)$$

$$k_{b,t,0} = k0_{b,t,0} . n_b \; ; \; \forall b \in B \; ; \; \forall t \in T \quad (15)$$

$$m_{b,v,0} = m0_{b,v,o} . n_b \; ; \; \forall b \in B \; ; \; \forall v \in V \quad (16)$$

$$l_{b,0} = Lb_o . nb \; ; \; \forall b \in B \quad (17)$$

$$k_{b,t,p} \geq 0 \; ; \; \forall b \in B \; ; \; \forall t \in T \; ; \; \forall p \in P \quad (18)$$

$$m_{b,v,p} \geq 0 \; ; \; \forall b \in B \; ; \; \forall v \in V \; ; \; \forall p \in P \quad (19)$$

$$x_{b,t,p} \in \{0,1\} \; ; \; \forall b \in B \; ; \; \forall t \in T ; \; \forall p \in P \quad (20)$$

$$y_{b,v,p} \in \{0,1\} \; ; \; \forall b \in B \; ; \; \forall v \in V ; \; \forall p \in P \quad (21)$$

$$n_b \in \{0,1\} \; ; \; \forall b \in B \quad (22)$$

$$u_t \in \{0,1\}\,;\ \forall t \in T \tag{23}$$

$$k_{b,t,p} \in \{0,1\}\,;\ \forall b \in B\,;\ \forall t\ \in T\,;\ \forall p \in P \tag{24}$$

$$m_{b,v,p} \in \{0,1\}\,;\ \forall b \in B\,;\ \forall v\ \in V\,;\ \forall p \in P \tag{25}$$

Constraints 2 and 3 determine the usage of the batteries and the terminals as charging stations. Constraint 4 limits to one the number of batteries that can supply energy to a vessel at each time step. Constraint 5 determines the battery charge level at every time step. It also guarantees that the power requirement from the vessel at each time step is satisfied. Constraint 6 bounds the battery level between the maximum capacity and a minimum battery level to avoid batteries to fully discharge (safety margin). It also guarantees non-negative values for the battery level. Constraint 7 sets a minimum battery level for the battery to be placed on a vessel. Constraint 8 limits the battery location to either a terminal or on a vessel, whereas constraints 9 and 10 match the vessels' routes to the batteries. Not allowing for a battery to move in the network if it is not on a vessel. Constraints 11 and 12 limit the maximum number of batteries that can be at a charging station and on a vessel according to the number of charging and charging spots respectively. Constraints 13 and 14 force the battery to be at a charging station to be charged and to be on a vessel to provide it with energy respectively. Constraints 15, 16, 17, 18 and 19 set the initial battery location, battery usage and battery charge level values. Finally, constraints 20 and 21 set the variables to be non-negative and constraints 22, 23, 24 and 25 defines the binary variables.

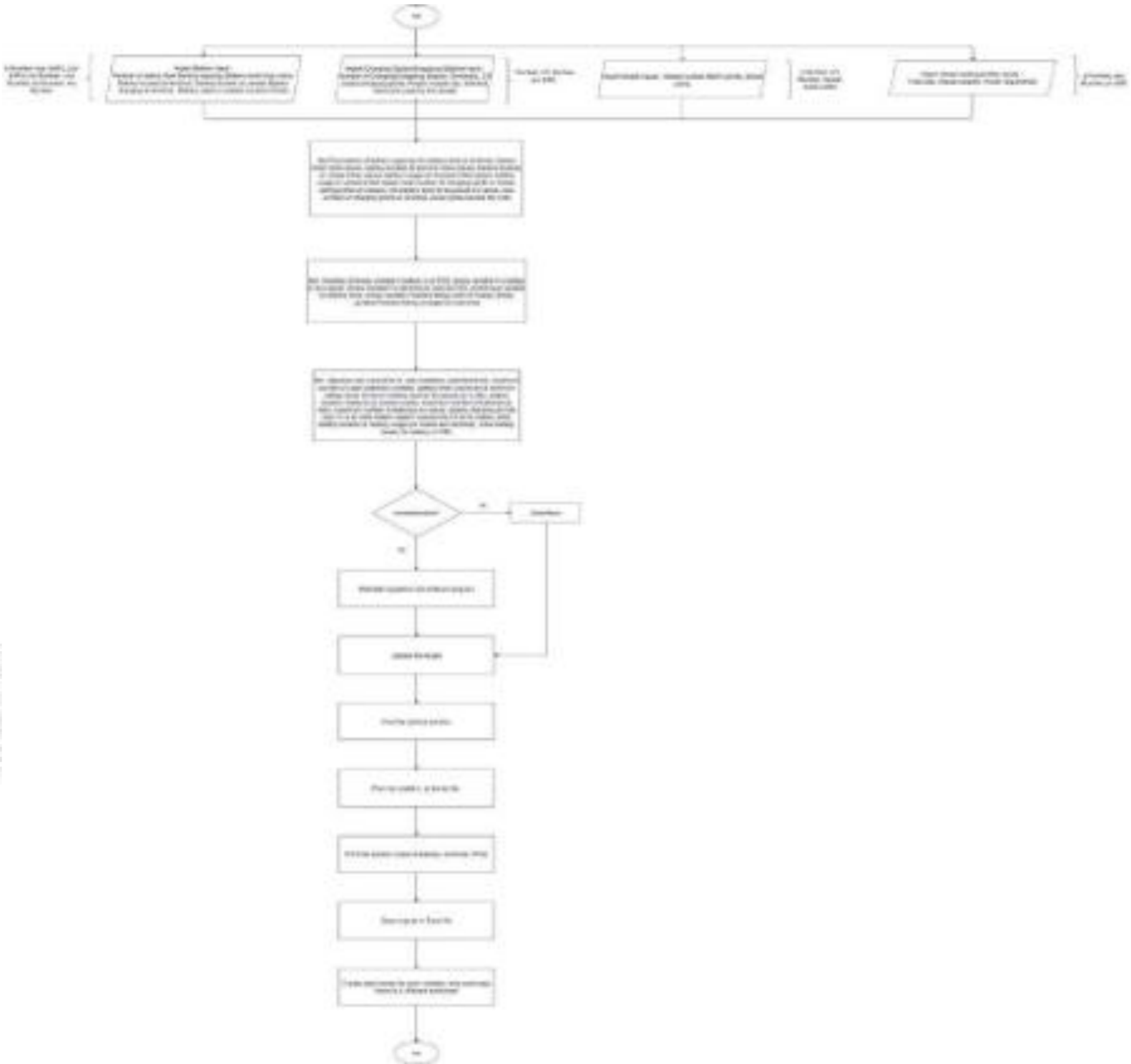

Figure 53: Algorithm Flowchart

5.8. Model Outputs

After writing and running the code, a brief summary of the result is given in the next figures.

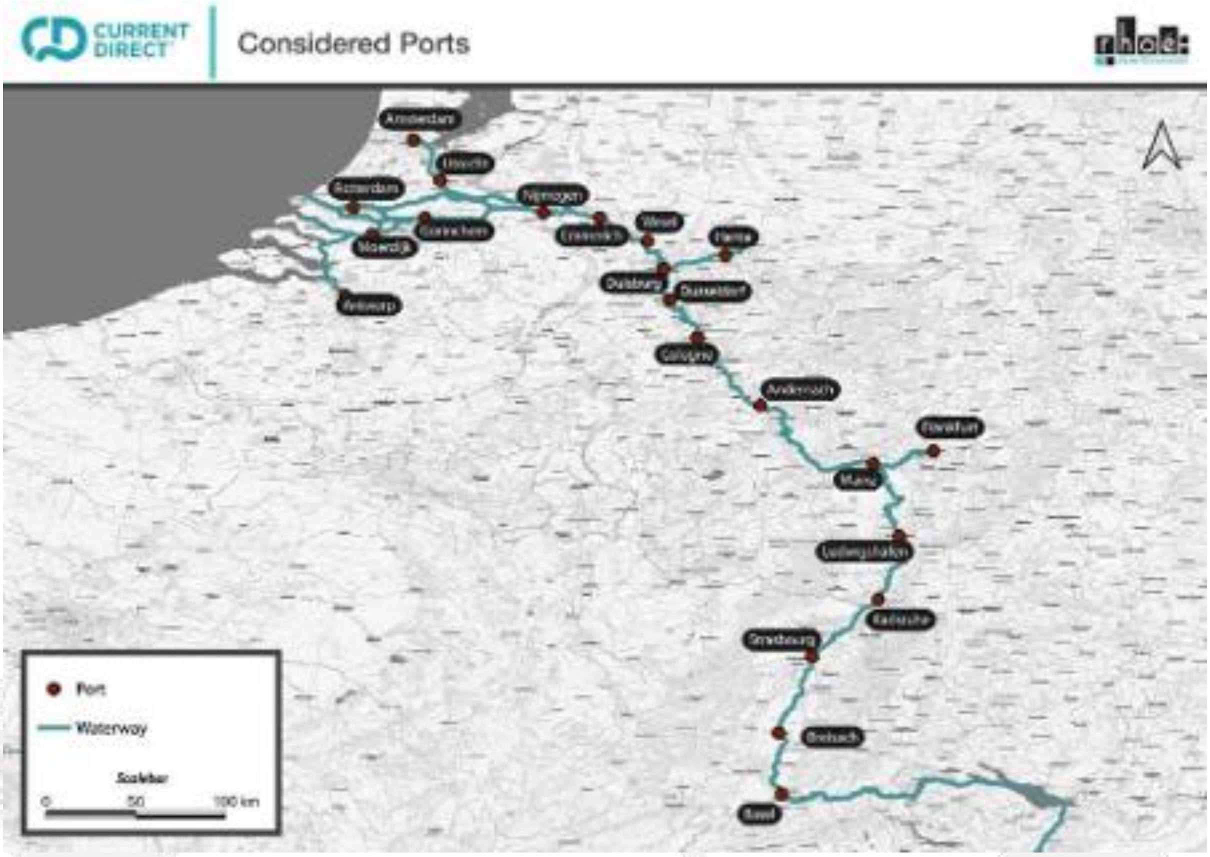

Figure 54: Considered Ports in Rhine Basin

Figure (54) shows the considered ports across the Rhine Basin. The next figures concern the journeys studied by Foreship from the Prominent Study (Figure (55)). The results show the ports that the vessel need to stop to swap the depleted batteries with new ones. For the time being, locks are not included as possible charging/swapping stations due to the current infrastructure. Future projections could also include locks as a possible charging/swapping station.

Journey	Port A	Port B	Considered Routes
1	Rotterdam	Duisburg	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg
2	Rotterdam	Antwerp	Rotterdam-Moerdijk-Antwerp

3	Rotterdam	Karlsruhe	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg-Dusseldorf-Cologne-Andernach-Mainz-Ludwigshafen-Karlsruhe
4	Amsterdam	Karlsruhe	Amsterdam-Utrecht-Nijmegen-Emmerich-Wesel- Duisburg-Dusseldorf-Cologne-Andernach-Mainz-Ludwigshafen-Karlsruhe
5	Rotterdam	Basel	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel Duisburg-Dusseldorf-Cologne-Andernach-Mainz-Ludwigshafen-Karlsruhe-Strasbourg-Breisach-Basel
7	Amsterdam	Antwerp	Antwerp-Moerdijk-Utrecht- Amsterdam
9	Amsterdam	Rotterdam	Amsterdam-Utrecht- Rotterdam
10	Antwerp	Mainz	Antwerp-Moerdijk-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg-Dusseldorf- Cologne-Andernach-Mainz
12	Antwerp	Duisburg	Antwerp-Moerdijk-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg
13	Rotterdam	Duisburg	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg
14	Rotterdam	Ludwigshafen	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg-Dusseldorf-Cologne-Andernach-Mainz-Ludwigshafen
16	Rotterdam	Strasbourg	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg-Dusseldorf-Cologne-Andernach-Mainz-Ludwigshafen-Karlsruhe-Strasbourg
18	Duisburg	Antwerp	Duisburg-Wesel-Emmerich-Nijmegen-Gorinchem-Moerdijk-Antwerp
22	Rotterdam	Herne	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg-Herne
23	Dusseldorf	Antwerp	Dusseldorf-Duisburg-Wesel-Emmerich-Nijmegen-Gorinchem-Moerdijk-Antwerp
25	Rotterdam	Duisburg	Rotterdam-Gorinchem-Nijmegen-Emmerich-Wesel-Duisburg

Figure 55: Table of Journeys studied by Foreship from Prominent List.

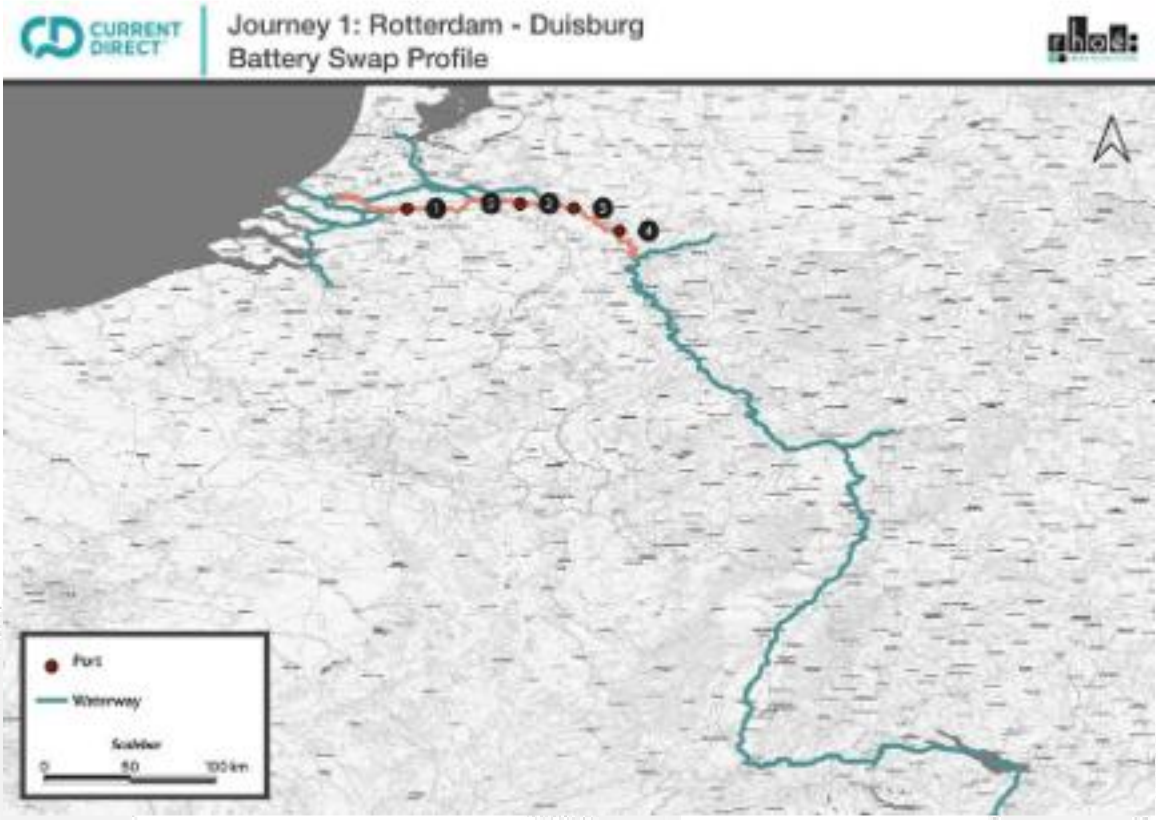

Figure 56: Battery Swap proposed for Journey 1 of the Prominent Study list

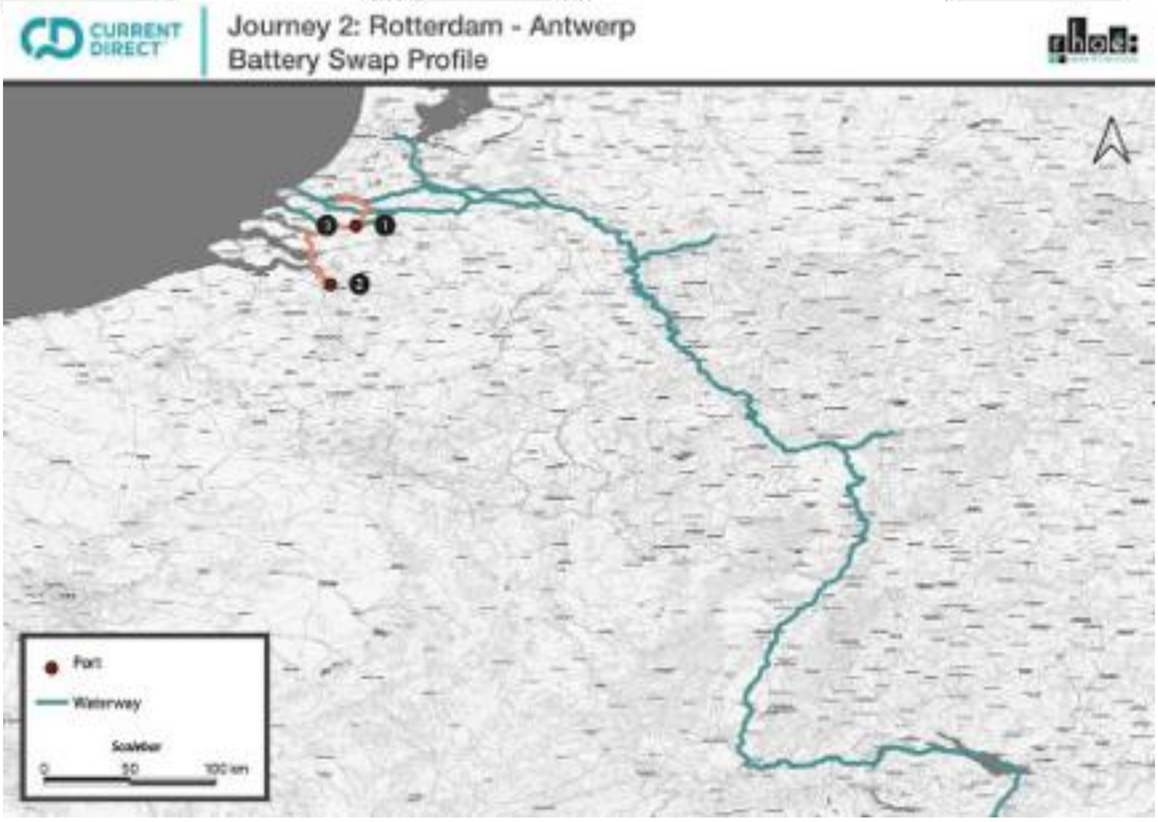

Figure 57: Battery Swap proposed for Journey 2 of the Prominent Study list

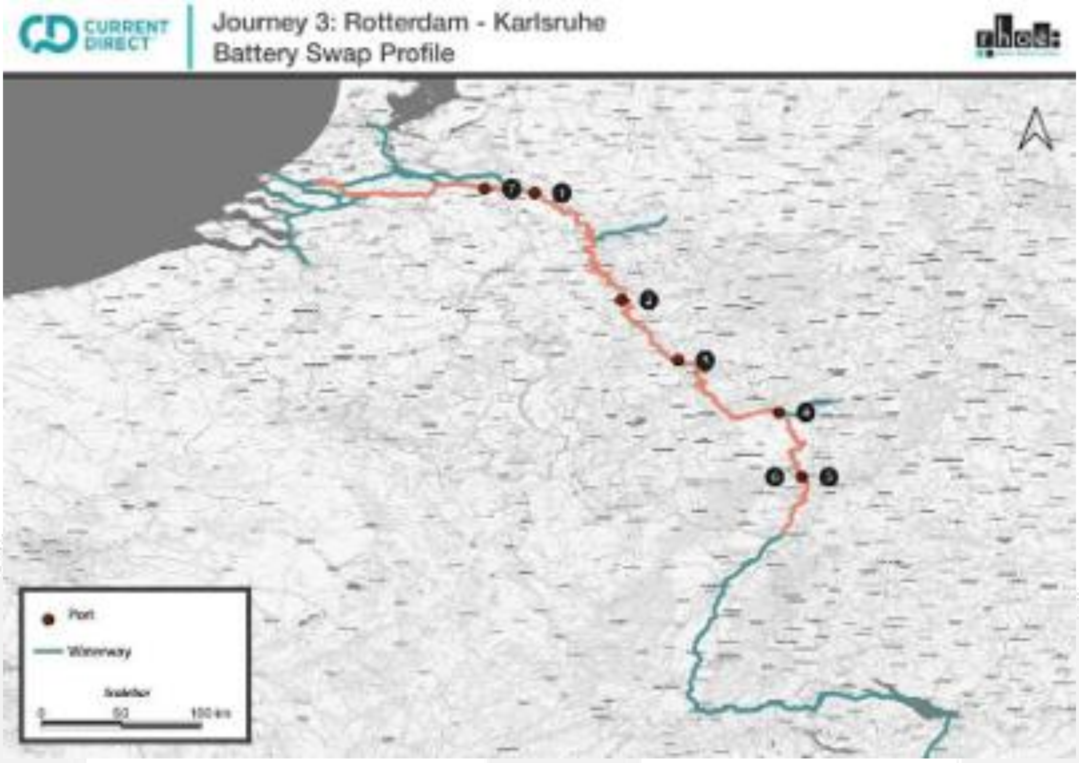

Figure 58: Battery Swap proposed for Journey 3 of the Prominent Study list

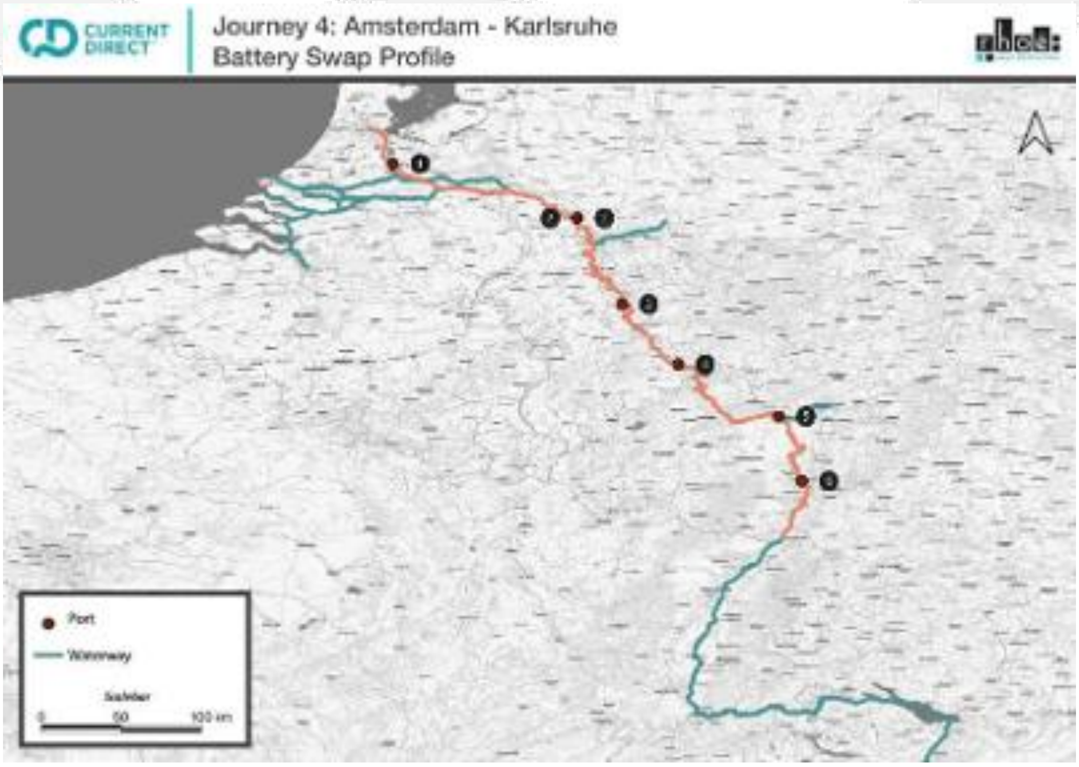

Figure 59: Battery Swap proposed for Journey 4 of the Prominent Study list

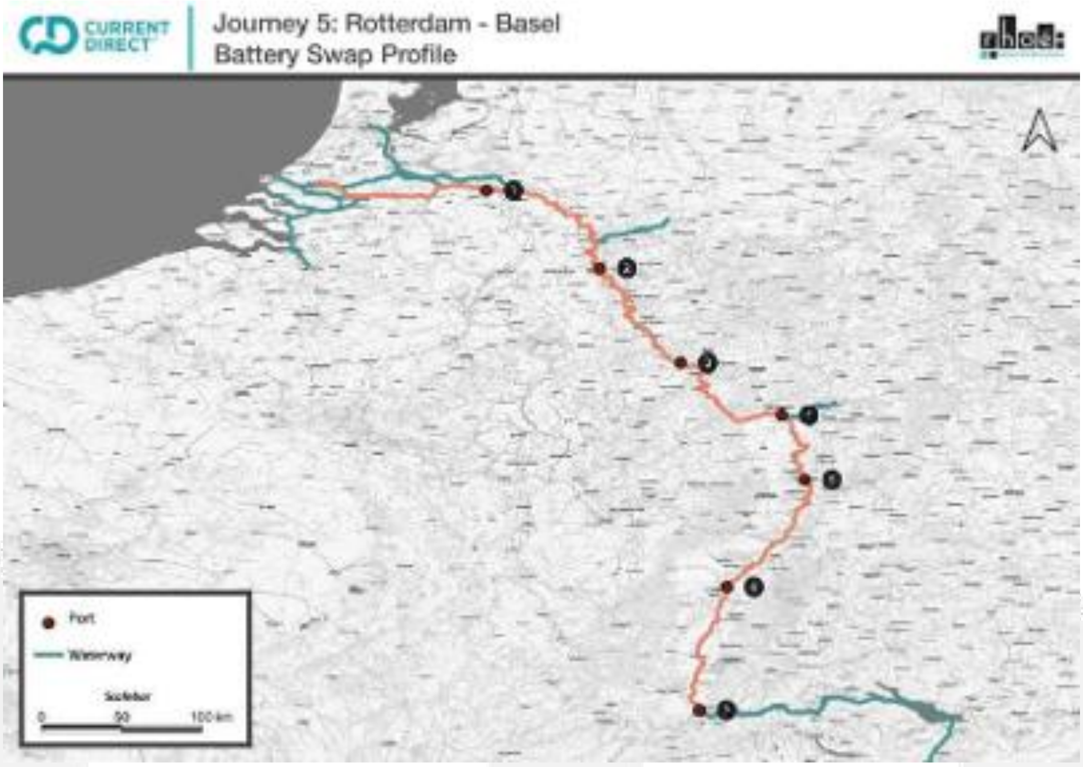

Figure 60: Battery Swap proposed for Journey 5 of the Prominent Study list

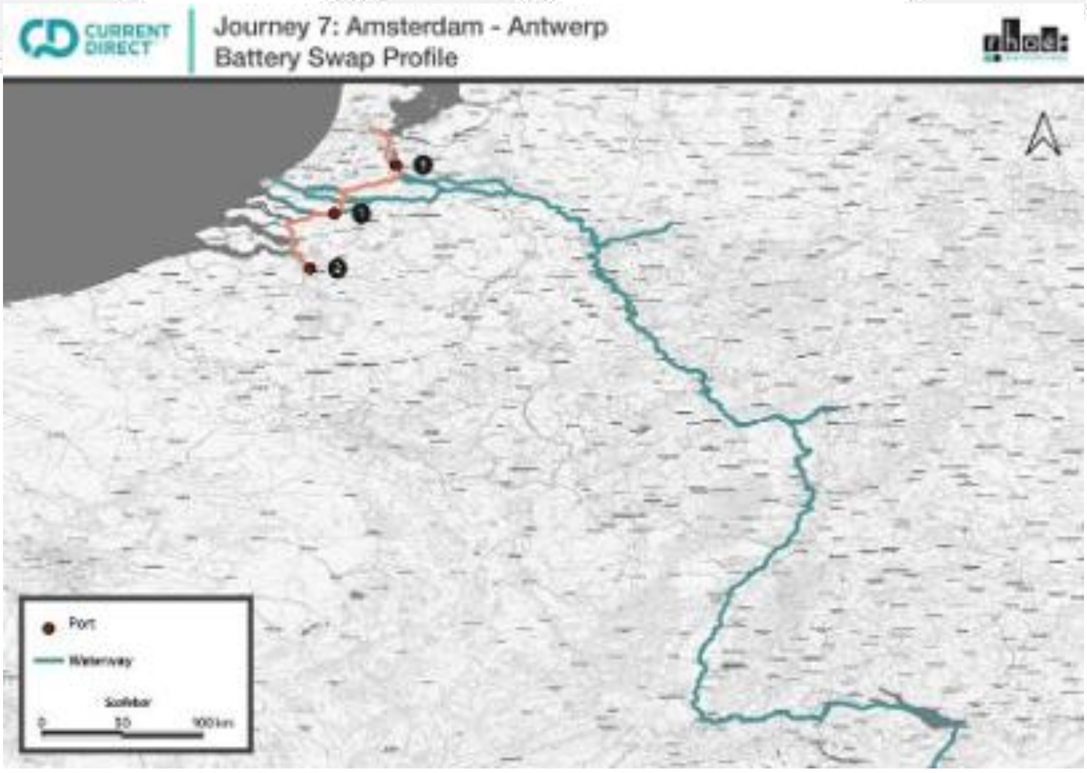

Figure 61: Battery Swap proposed for Journey 7 of the Prominent Study list

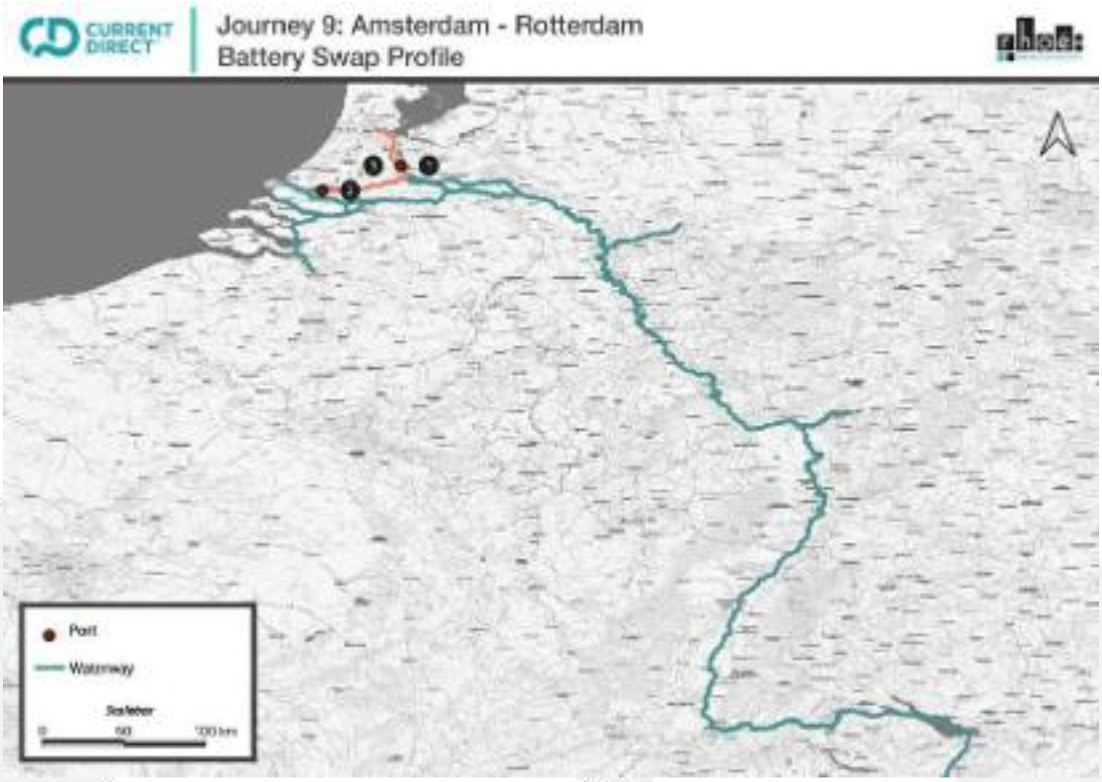

Figure 62: Battery Swap proposed for Journey 9 of the Prominent Study list

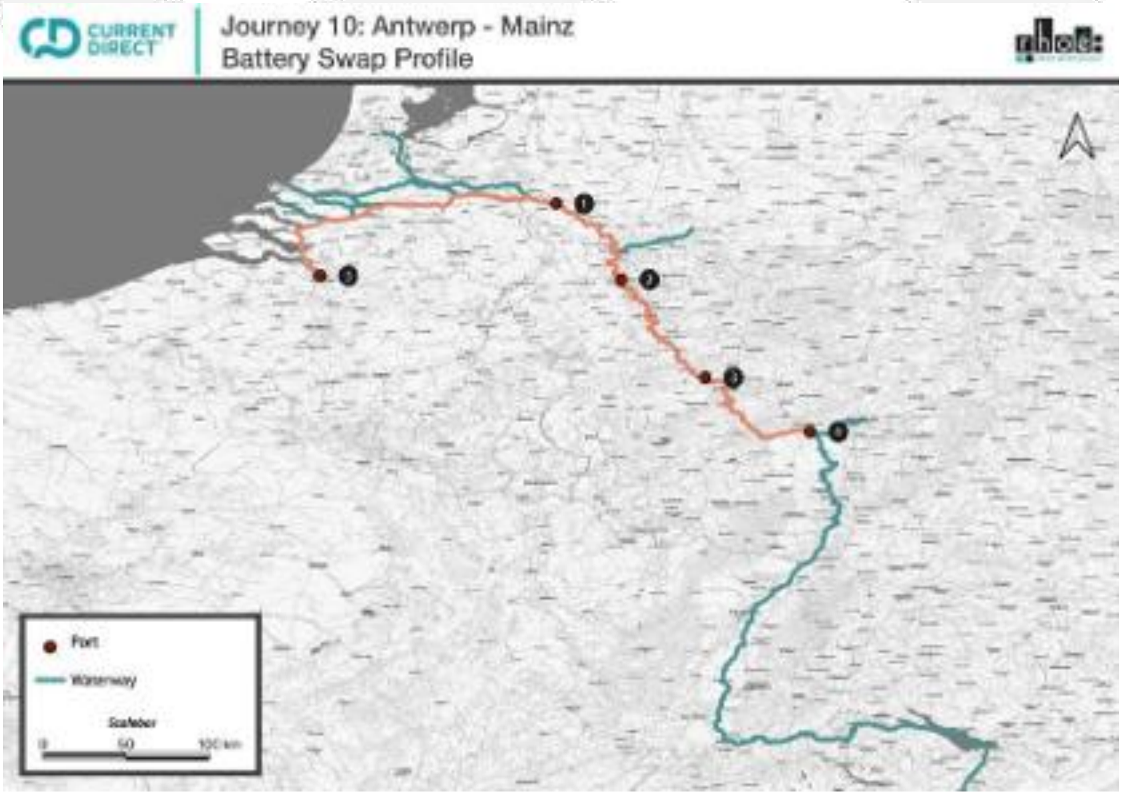

Figure 63: Battery Swap proposed for Journey 10 of the Prominent Study list

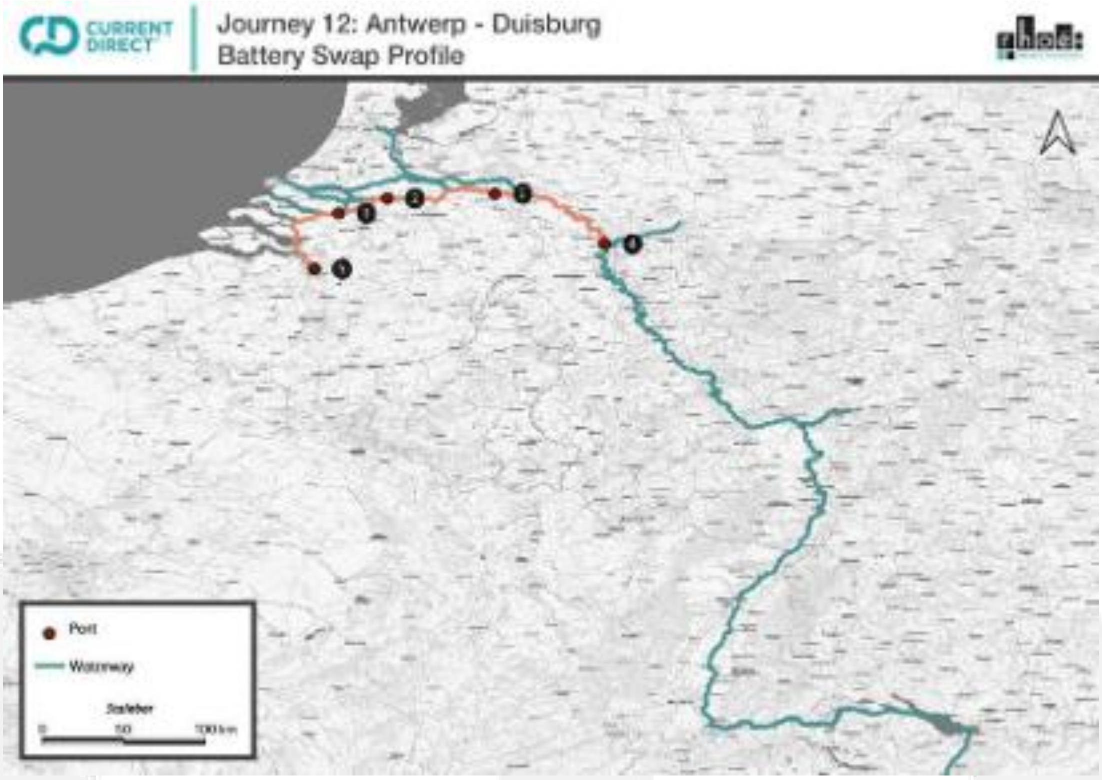

Figure 64: Battery Swap proposed for Journey 12 of the Prominent Study list

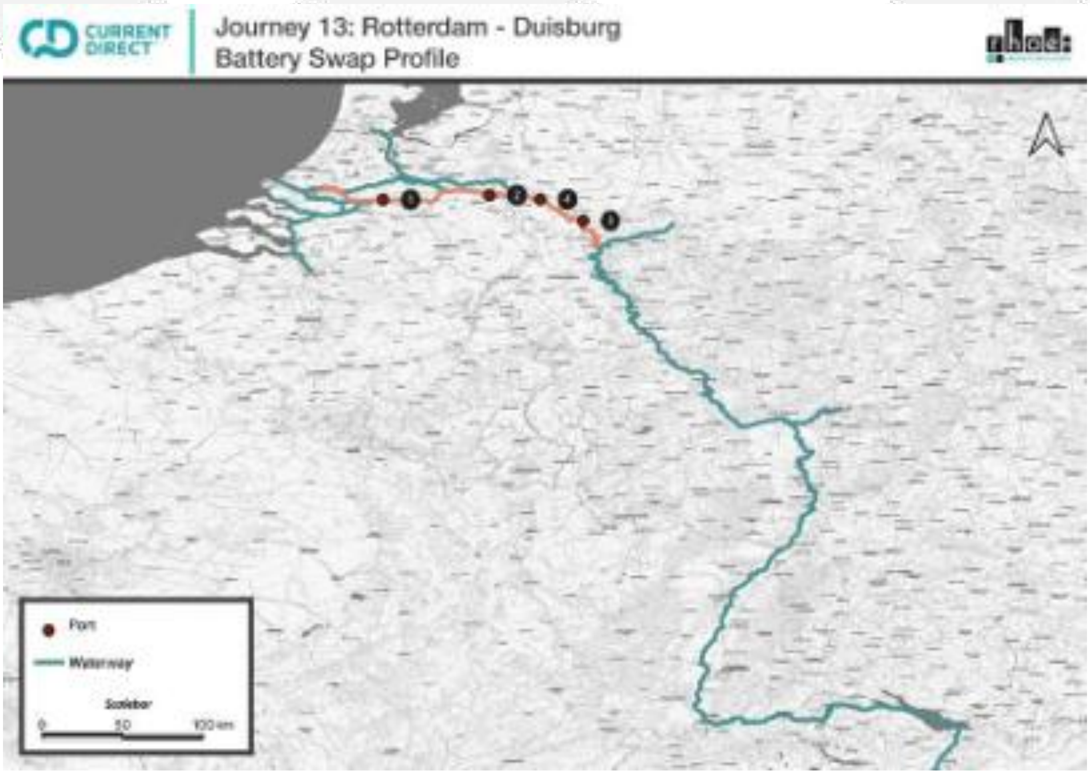

Figure 65: Battery Swap proposed for Journey 13 of the Prominent Study list

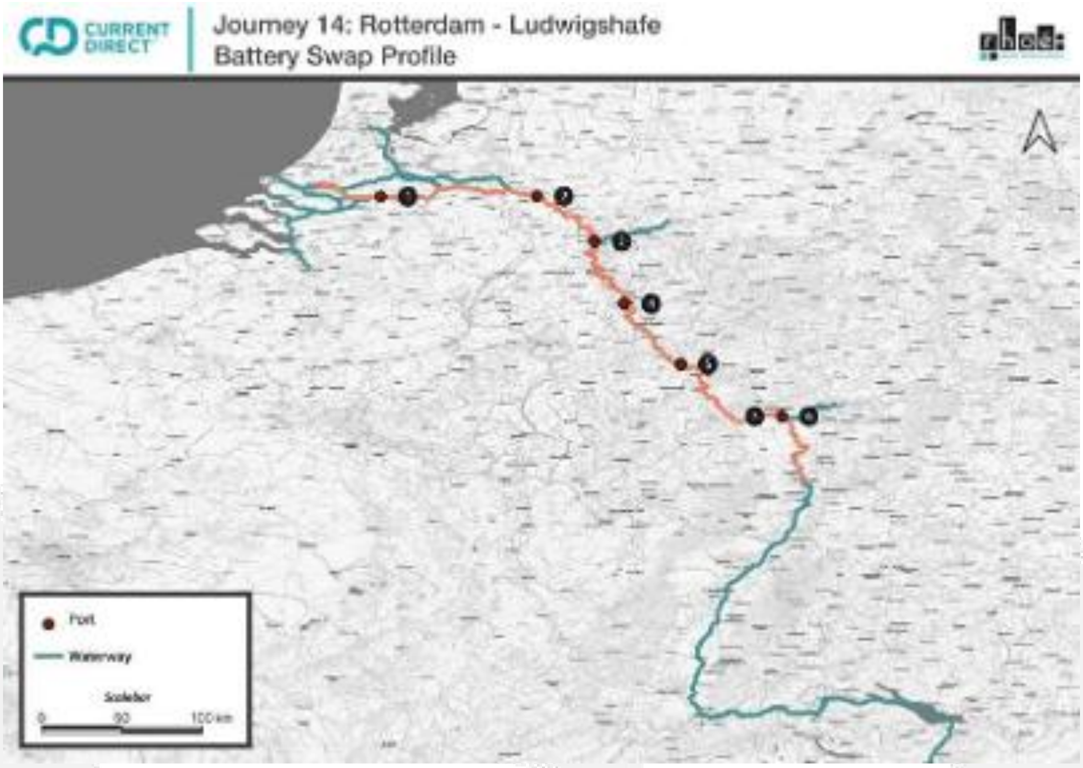

Figure 66: Battery Swap proposed for Journey 14 of the Prominent Study list

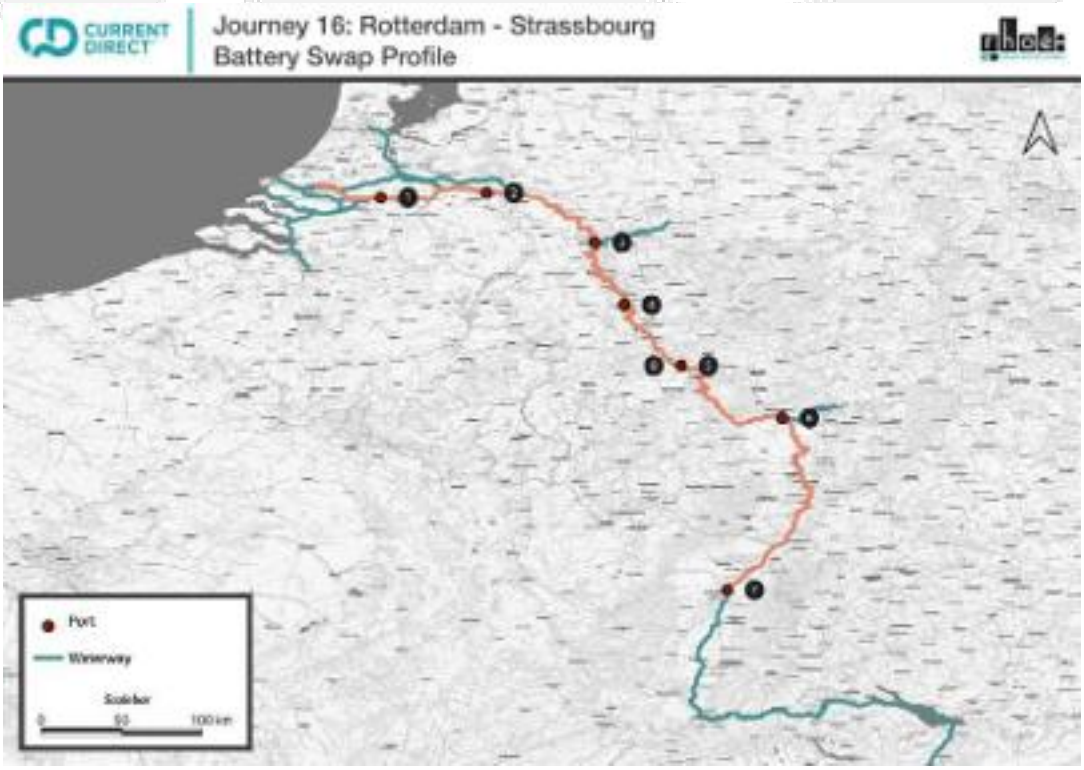

Figure 67: Battery Swap proposed for Journey 16 of the Prominent Study list

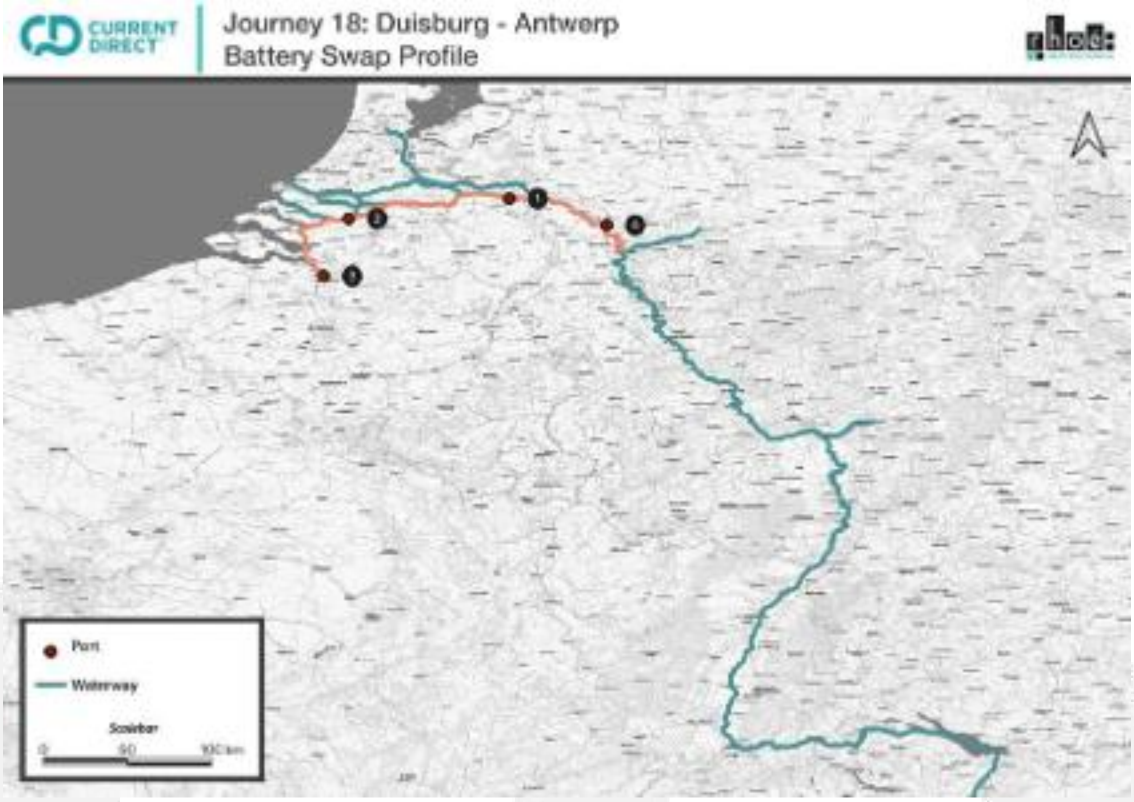

Figure 68: Battery Swap proposed for Journey 18 of the Prominent Study list

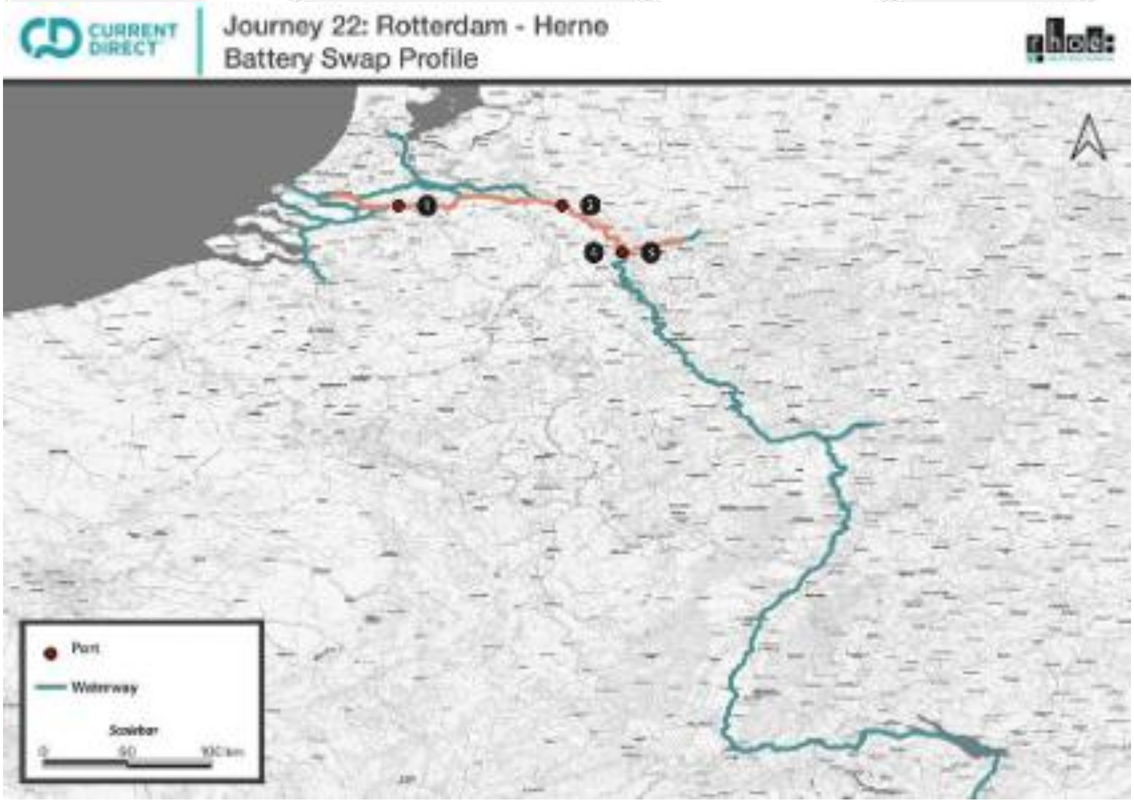

Figure 69: Battery Swap proposed for Journey 22 of the Prominent Study list

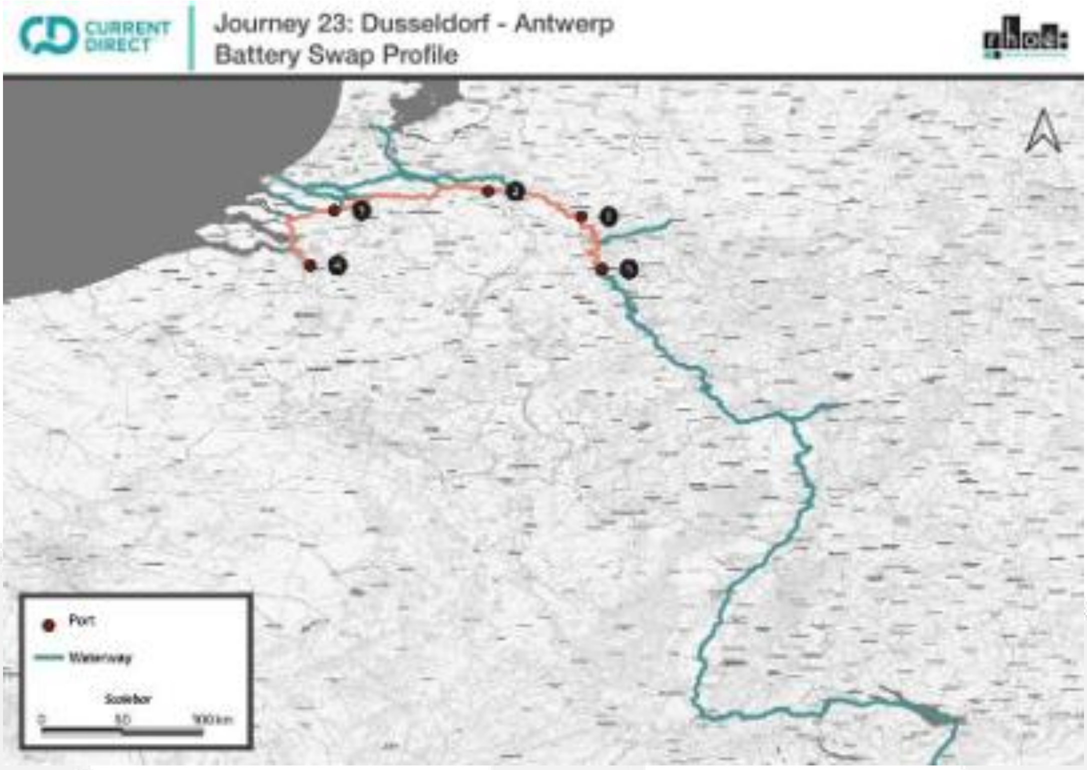

Figure 70: Battery Swap proposed for Journey 23 of the Prominent Study list

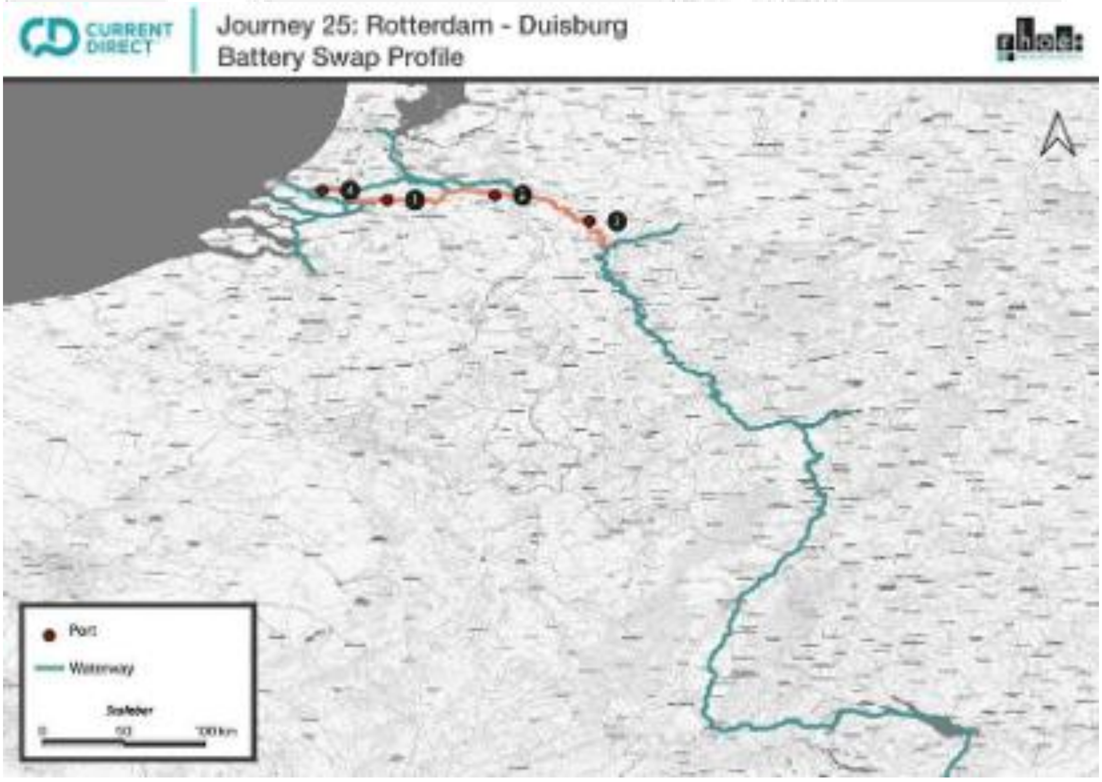

Figure 71: Battery Swap proposed for Journey 25 of the Prominent Study list

As seen in figures above, the algorithm that was executed with dummy data for specific journeys and specific vessels from Prominent List lead on the ports that the Charging Stations of Current Direct Project will be. In addition, thorough the algorithm the number of the batteries needed for each vessel journey was assessed and the battery swap proposition was introduced.

6. CONCLUSIONS - NEXT STEPS

In conclusion, concerning Phase 3 and more specifically the electrical grid infrastructure assessment, further information is to be retrieved from the stakeholders at the port to better understand the current and future electric connections and network charges at the port. A questionnaire has already been sent to the main entities which should provide the necessary inputs for the task. Concerning Phase 4 - Assessment of Current Direct Infrastructure Requirements once the development of the algorithm will be finished, the results that is previously shown along with outputs like the number of the batteries each station should have, the size of the charging station and the future Infrastructure Requirements will be integrated into the Energy as a Service (EaaS) Platform of the Current Direct Project after the initial running of the algorithm with real data. Furthermore, the results will be used as inputs for the development of Charging Scheduling algorithm that will also be running through EaaS Platform. The combination of these two algorithms will give the wanted results and will improve our initial solutions for the Current Direct Infrastructure.

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APPENDIX

Appendix A – Questionnaire – Grid Infrastructure Assessment

Electricity Pricing policies and electrical port's infrastructures questionnaire

February 8, 2022

1. Questionnaire

4.1. Port's electricity pricing policies and power network structure

1) Has the port a private internal power grid?
2) Who is the energy retailer selling electricity to the port?
3) Which voltage level is the internal grid connected to the public grid?
4) How many different customers/consumption points are there in the port? And which is their voltage level?
5) Is the port's internal power grid managed by one entity (e.g., grid owner)? If yes, do the port's consumers have a specific electricity contract with the electricity retailer or it is all managed by the internal grid owner? (example: is there one company specifically responsible for managing electricity and the internal grid within the port?)
6) Where are the electricity meters (consumption points) is there one specific meter for each type of consumer?
7) Do industrial consumers (within the port) pay a multi-component tariff that includes both Capacity and Volume of energy? And what type of tariff is applied to the volume part (fixed price, time-of-use, real-time energy price)? (For example: consumers only pay a fixed charge in euros OR consumers pay a fixed charge, a power-related charge in €/MVA and a constant €/kWh parcel OR consumers pay a fixed charge and 3 different €/kWh prices depending on the time of the day)
8) What are the connection costs in case the grid needs to be extended?
9) Are you aware if specific tariff conditions are in place for battery charging and storage devices applications? (For example: do battery pay as if they are other consumers, do they pay network costs when they inject power back to the grid?)

2. Port's available infrastructures (WP6.8)

1) What is the currently available infrastructure in the port (e.g., a list with crane availability, berth availability, number and lifting capacity of machineries and other equipment such as container bridges, container cranes and mobile cranes that can be used for the battery swapping infrastructure)?
2) What is the constraint regarding the grid capacity in the port? Which is the available area that a port can provide for the infrastructure deployment?
3) Is there an area in the vicinity of existing cranes that could be used for storing and charging containers?
4) Can you provide us with details about the port's connectivity? (If there is a network connection available throughout the port)

5) Can you provide us with details about the port's fluctuation? (If the port works 24 hours a day or there is a specified vessel schedule)

3. Safety

1) Do the port have a safety policy for storing energy storage containers?