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AUTOFLEX

[D3.1] Transport Concepts

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EXECUTIVE SUMMARY

This report constitutes the D3.1 deliverable of the AUTOFLEX project, which is based on the tasks 3.1, 3.2, and 3.3 of the project, as outlined in section 1.3 . The deliverable is a conceptualization report describing the concepts of Stow&Charge hubs, Temporary port terminals, and Mobile Distribution Centres developed within these tasks. The report includes the design choices and how these have been made based on requirements, logistical performance, and discussions both within the project group and with advisory board members. It also includes the identified requirements related to the concepts, relevant regulatory challenges and needs for approval.

The temporary port terminal (TPT) concept has been developed as a solution for transferring cargo over berths that are currently not equipped for cargo handling. Candidate berths have been identified and studied as part of the concept development. The candidate berths were identified by investigating population density and road traffic intensity, to find the areas with high external cost impact. The waterway alternatives to the road traffic intense corridors were identified, and then the areas along these waterways with high density of potential customers. Finally, a gap analysis was done to distinguish the un- and under-utilized waterways from those with existing transport services, leading to a reduced set of potential transport customer clusters which were scrutinized to find concrete potential TPT locations. The key functionalities of TPTs have been derived from the identified potential TPT locations, and a set of possible ways to realise the functionalities have been proposed. The result is a modular concept making it possible to adapt a TPT to local conditions and transport demand.

The combined energy and cargo hub, the Stow&Charge (SCH) concept has been developed and is a cargo hub that connects electric trucks and inland vessels, provides efficient transfer between the modes, and supplies electricity produced at the hub. Produced energy is stored in battery containers (ZES packs), which can be loaded onto vessels or be the energy source for charging vessels and trucks. The required infrastructure has been mapped, and a terminal layout has been investigated to identify areas where solar and wind farms can be installed, without interfering with cargo operations. Production and capacity requirements have been considered in the investigations to ensure that electric trucks and inland vessels operating from a Stow&Charge terminal can be supplied with electric energy. A total of 28 locations have been evaluated, and a recommendation for the most suitable terminals is provided.

The Mobile Distribution Centre (MDC) concept has been developed in order to open up a market segment currently unavailable to inland waterway transport (IWT), i. e., less-than-vessel (LVL) loads. With the help of a novel transport equipment unit, the distribution of individual consignments is to be realised. As the small, flexible, automated, zero-emission (SFAZ) inland vessel of the project is designed for the container transport case, an ISO container has been selected as the base form with which individual consignments of a customer can be transported, transhipped, stored at designated locations, and provided for comfortable and swift collection from there. Such locations can be existing port terminals but also additional locations along the waterway, including city centres, industrial parks, and further TPT locations. The MDC concept was developed through a structured approach based on workshops, stakeholder interviews, and surveys. This process first identified a set of high-level concepts and ideas, which were scrutinized and reduced to the most promising concepts. These were further developed into drafts that were once more scrutinised until a final MDC

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concept was chosen. This final concept was developed in detail and realised in the form of a hybrid demonstrator with both physical and virtual features.

The overarching motivation for the work presented in this deliverable is to reduce road transport and foster the attractiveness of IWT as a measure to reduce greenhouse gas emission specifically, and external costs in general. The idea for achieving this has been to extend the reach of inland waterway transport services into smaller un- and under-utilized waterways. To achieve this, strengthening small and medium-sized ports (SMP) has been identified as a key to success, and because one of the main challenges for SMPs is limited financial strength, reducing investment risk has been an important design criterion. The proposed SCH, TPT, and MDC concepts deliver on this through being modular, which enables scalability and adaptability, making it possible to start small and grow, and to relocate assets if market conditions changes.

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LIST OF ABBREVIATIONS

Abbreviation	Description
€/kW	Euro per kilowatt
€/kWp	Euro per kilowatt peak
€/m²	Euro per square meter
AAB	AUTOFLEX Advisory Board
a-Si	Amorphous Silicon
AUTOFLEX	Autonomous small and Flexible vessel
BoL	Beginning of Life (battery condition)
CAPEX	Capital Expenses
CdTe	Cadmium Telluride
CEMT	Conférence Européenne des Ministres des Transports
CIGS	Copper Indium Gallium Selenide
DFDS	Det Forenede Dampskibs-Selskab
EoL	End of Life (battery condition)
FCL	Full container load
FPV	Floating Photovoltaic
FTL	Full truck load
FVL	Full vessel load
GT	Gross Tonnage
GW	Gigawatt
GWh/a	Gigawatt hour per annum
Ha	Hectare 10.000 square meters
ISPS	International Ship and Port Facility Security Code
IWT	Inland Waterway Transport
km/h	Kilometres per hour
kW	Kilowatt
kWh	Kilowatt hour
kWp	Peak Power (Kilowatt peak)
LCL	Less-than container load
LFP	Lithium-Iron-Phosphate
LTL	Less-than truck load
LVL	Less-than vessel load
m	Meter
m	Meter
m/s	Meter per second
m²	Square meter
MCS	Megawatt Charging System
MDC	Mobile Distribution Centre
MSOA	Modal Shift Opportunity Area
MST	Modal Shift Targets
MW	Megawatt
MWh	Megawatt hour
MWp	Megawatt peak
OPEX	Operational Expenses
PV	Photovoltaic
SCH	Stow&Charge Hub
SFAZ	Small, Flexible, Automated, Zero-emission
SMP	Small-to-Medium Port
SMP	Small Medium sized Port
SOTA	State-of-the-art
SRP	Schottel Rudder Propeller

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TCO	Total Cost of Ownership
TEU	Twenty-foot Equivalent Unit
TPT	Temporary Port Terminal
USD	United States Dollar
WP	Work Package
WTE	Water-to-Energy
ZES	Zero Emission Services
ZESpack	Zero Emission Services battery container

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1 INTRODUCTION

1.1 THE AUTOFLEX PROJECT

The AUTOnomous Small and FLEXible vessels – project (AUTOFLEX) is a Horizon Europe funded project that targets expansion of waterway transport into small and underutilized canals. The primary goal is to develop technology and concepts that enables a modal shift from road transport to zero-emission inland waterway transport (IWT). The project approaches this problem from several angles.

Firstly, highly populated areas, such as the Randstad region in the Netherlands (see section 2.1), are connected by a dense waterway network and could be serviced by vessel transport. However, these waterways have little to no traffic related to cargo transport, while road traffic is intense with significant congestion challenges. The main reason is that these underutilized waterways are small (CEMT 2-3), and there is currently no business case for operating cargo services on them. The project approaches this issue by developing small (CEMT 2) uncrewed battery-electric vessels. These vessels are designed, by exploiting the increased design freedom from having no crew onboard, to obtain higher container capacity than traditional designs [1]. Furthermore, as the vessels are uncrewed and operated from a remote operation centre, they will achieve reduced operating costs and increased operating time.

Secondly, having vessels that offer increased efficiency in terms of cost and time creates opportunities. However, a successful business case for a transport service on these small waterways depends on more than promising vessel designs. In addition, an efficient transport system is needed, and this is the scope of AUTOFLEX work package 3.

1.2 WORK PACKAGE 3: DEVELOPING AUTOMATED MULTIMODAL ZERO-EMISSION TRANSPORT SYSTEMS

As there are little to no waterborne transport services on the CEMT 2 waterways of AUTOFLEX Use Case 1 (section 2.1) today, there is also a lack of transhipment and energy infrastructure. Furthermore, a part of the truck transport, which is desirable to move to waterborne transport, is part loads (i.e., not full container loads). *Work Package 3: Developing automated multimodal zero-emission Transport Systems* aims to address these key gaps in the realisation of efficient zero-emission transport systems, by developing the necessary infrastructural and operational components. Central to this vision is the establishment of a multimodal transport framework that minimizes reliance on conventional truck transport for urban distribution, thereby reducing congestion and emissions in city environments.

To support system design and deployment, Work Package 3 focuses on generating detailed operational profiles for vessel configurations through the identification of representative transport tasks on small inland waterways. A critical aspect of this endeavour involves the conceptualisation of integrated energy and cargo hubs, aptly named “Stow&Charge”, tailored to the specific requirements of zero-emission logistics chains. In parallel, Work Package 3 explores the feasibility of “Temporary Port Terminals” (TPTs) as scalable, cost-effective solutions for cargo transfer in underutilized or infrastructure-limited berths. Further augmenting the logistics architecture, “Mobile Distribution Centres” (MDCs) are introduced as

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mobile, adaptable components within the broader supply chain, aimed at enhancing the flexibility and sustainability of last-mile delivery. These innovations are accompanied by a systemic re-design of the transport network architecture, culminating in the implementation of the holistic AUTOFLEX system. The integrated system will undergo rigorous validation to assess its performance, reliability, safety, security, and resilience under real-world conditions. Finally, Work Package 3 also investigates the integration of renewable energy sources to ensure that the electrification of transport aligns with broader climate and sustainability goals, thereby reinforcing the environmental viability of the AUTOFLEX approach.

1.3 SCOPE OF THE DELIVERABLE

The scope of this deliverable, *AUTOFLEX [D3.1] Transport Concepts*, includes the Stow&Charge, TPT, and MDC concepts developed within work package 3. The task descriptions, as given in the Grant Agreement (framing the ambitions for these concepts are given in the following. The AUTOFLEX transport system, based on the concepts presented herein, will be addressed in the subsequent deliverable *AUTOFLEX [D3.2] Transport System*.

1.3.1. TASK 3.1: COMBINED ENERGY AND CARGO HUBS (STOW&CHARGE)

This task will develop a concept for a combined energy and cargo hub that connects electric trucks and inland vessels, provides efficient transfer between the modes, and supplies both modes with electricity produced at the Stow&Charge hub. Produced energy is stored in ZES-packs which can be loaded onto vessels or be the energy source for charging vessels and trucks, etc. Zero-emission transport requires efficient distribution of both cargo and energy. The AUTOFLEX project focuses on battery electric energy as the means to provide ZEM transport services. As there is an under-capacity in electric energy supply in Europe, electrification of transport can only have a positive climate impact if it includes the establishment of production of electric energy from renewable sources. Energy production requires both space and investments, which could be provided by terminal owners and operators like DFDS.

Method: Terminal layout will be investigated to identify areas where solar and wind farms can be installed, without interfering with cargo operations. The required infrastructure will be mapped, and a layout developed. The logistical and performance analysis of Task 3.5 will serve as input for production and capacity requirements to ensure that all electric trucks and inland vessels operating from the terminal can be supplied with electric energy.

The task has been completed as described above, and the outcome is presented in chapter 6 .

1.3.2. TASK 3.2: TEMPORARY PORT TERMINALS

This task will investigate concepts for transferring cargo over berths that are currently not equipped for cargo handling. Potential concepts have been studied by AEGIS, where the inland vessel carries a tugmaster that is moved to land to perform the cargo handling, and NOVIMAR, which developed a crane that can drive on and off the inland vessel while carrying containers. Other possibilities for using such berths for cargo transfer include transport of RoRo containers, investing in cargo handling equipment at the berth, and new business models for cargo handling as a service based on mobile cargo handling equipment that is moved between locations.

Method: The results from Task 2.1 will provide candidate berths for each use case. The temporary port terminal concept will then be developed by first establishing a set of possible

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solutions (including existing concepts), and by evaluating the application of the solutions in the use cases by a cost benefit analysis (where cost is traded off against logistical performance). Requirements for permits and regulatory challenges such as related to ISPS will be mapped and procedures for complying with these will be developed.

The task has been completed as described above, and the outcome is presented in chapter 5 6 . Notice that according to the scope definition of [2] and [3], the AUTOFLEX vessel is not subject to ISPS, which is why chapter 5 6 does not consider compliance to ISPS, but rather discuss safety and security measures.

1.3.3. TASK 3.3: MOBILE DISTRIBUTION CENTRES

This task will investigate concepts for Mobile Distribution Centres (MDCs), and study the logistics related to these. Existing MDC solutions include LoLo and RoRo containers that are converted to hold smaller standardised cargo units that are easily transferred to last mile distribution vehicles. The MDCs are transported and placed in a central location for last mile urban distribution. The MDCs are packed with smaller cargo units that can be loaded directly unto small electric vehicles, such as in the KoMoDo project, for the last mile transport of the parcels within the small cargo units. The task will study MDC concepts in terms of how they can be distributed and placed, including how they are moved onto and from the vessels. It will also be considered whether distribution from MDCs while they are onboard inland vessels is a viable solution.

Method: Workshops and stakeholder interviews will determine which mobile distribution centre concepts are chosen for further studies, as well as for identifying potential changes to the concepts to make them more efficient. Furthermore, the logistics model will be expanded to include these concepts; an MDC model, a distribution demand model and an MDC packing model will be added. Logistical simulation and performance quantification study will be performed to validate the concept in Task 3.5.

The task has been completed as described above, and the outcome is presented in chapter 7 .

1.4 THE AUTOFLEX VESSEL

The analysis of potential use cases, for Temporary Port Terminals (TPTs – see chapter 5) and Stow & Charge hubs (see chapter 6) strongly depends on the developed zero-emission AUTOFLEX vessel and its operational profiles. The following section summarizes the vessel's design characteristics, propulsion and energy systems, and typical operational patterns within the defined use cases. This information is essential for the determination of the energy demand at terminals and for the definition of the requirements for combined energy and cargo hubs, and for TPTs.

The AUTOFLEX vessel [4] is a fully electric and unmanned CEMT II inland waterway vessel developed specifically for zero-emission operations along waterways in the Netherlands and Belgium. Its compact dimensions, energy-efficient hull form and modular battery design (see Figure 1-1) make it particularly well suited for regular corridor-based transport services, where predictable energy demand and frequent terminal calls can be aligned with the TPT and Stow & Charge concept. With an overall length of 55.00 metres, a beam of 6.60 metres and a depth of 2.60 metres, the vessel fits well within the standard operational envelope of CEMT II waterway infrastructure, allowing unobstructed navigation through the majority of locks, bridges and terminals in the Netherlands and Belgium. At a design draft of around

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1.93 metres, the vessel achieves a deadweight of 532.6 tonnes and provides capacity for up to 24 TEU arranged in a single cargo hold optimised for efficient handling.

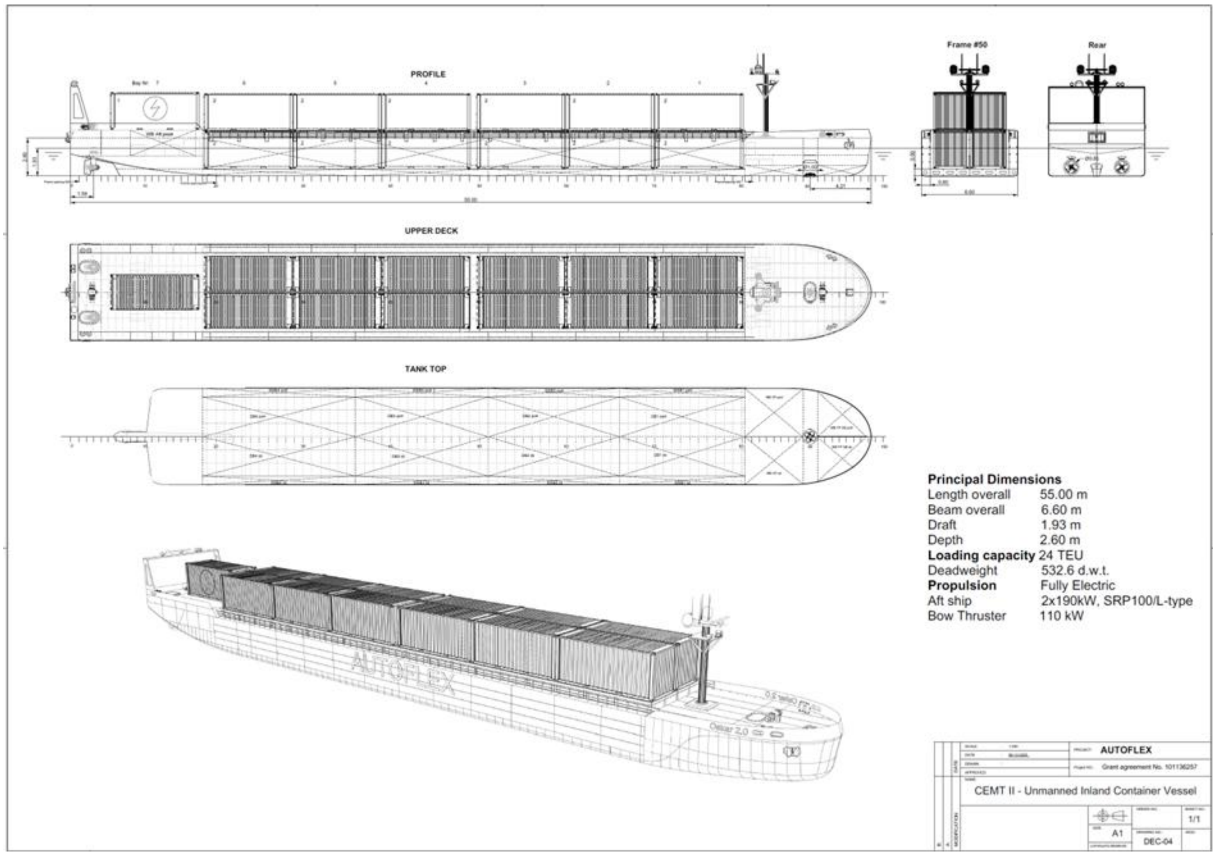

Figure 1-1: General Arrangement Plan of the AUTOFLEX Inland Container Vessel

1.4.1. HEIGHT ABOVE WATER (AIR DRAFT)

The vessel dimensions will be taken into consideration when each location is analysed vis-à-vis their relevance towards the TPT concept. Another important aspect, at least for some potential TPT locations, is the vessel height above water (air draft). There are some areas which have restricted access due to fixed bridges limiting the maximum allowable vessel height. The height above water for the AUTOFLEX vessel depends on the carried weight, and on the placement of the battery container. If the ZESpack is placed in the cargo hold, the vessel TEU capacity is restricted to 20 TEU, but a height above water between 2.52 and 3.22 meters can be achieved. If the ZESpacks are placed on the poop deck, as the design intends, the TEU capacity will be 24 TEU, but the height above water will be between 3.82 and 4.99 meters, depending on the loading condition, see Figure 1-2.

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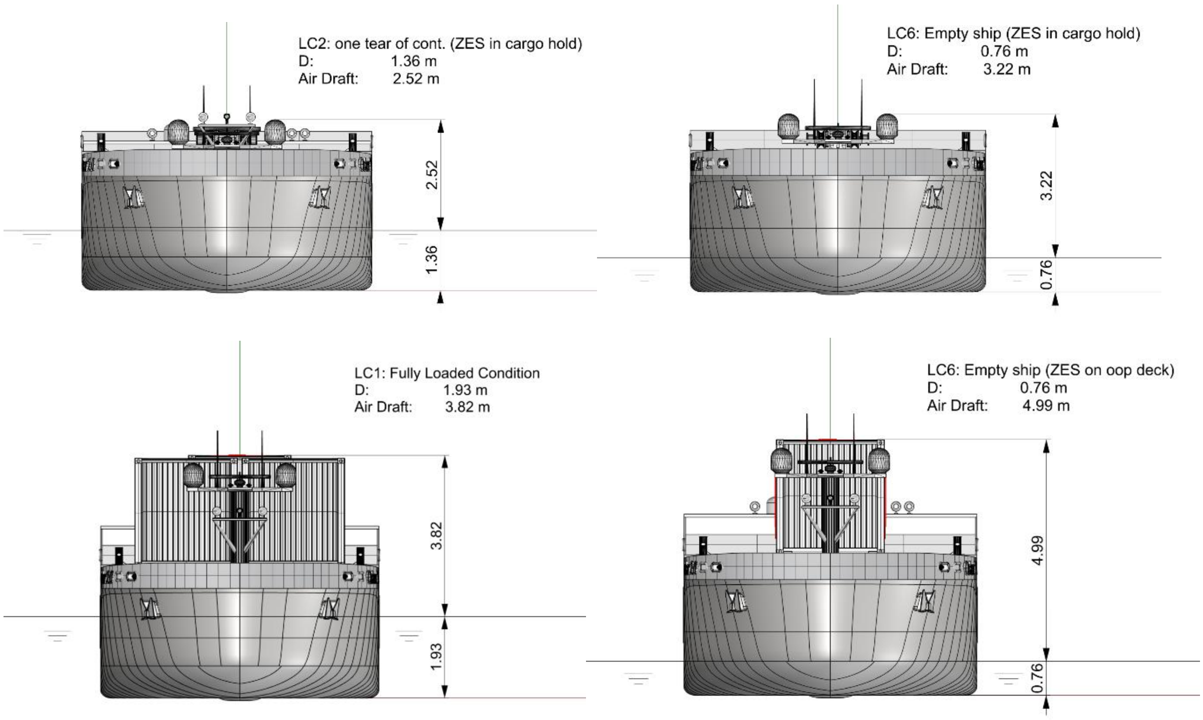

Figure 1-2: AUTOFLEX vessel height above water for different loading conditions

1.4.2. AUTOFLEX VESSEL POWERED BY EXCHANGEABLE BATTERY CONTAINERS

The vessel's design aims to enable a zero-emission transport based on a modular energy concept using a swappable electrical battery container (ZESpack) [5]. This approach reduces the need for large integrated battery rooms and allows sufficient energy exchange at equipped terminals. The fully electric propulsion arrangement is realized by two 190 kW Schottel SRP100/L azimuth thrusters [6] located in the aft body and a 110-kW bow thruster, providing both propulsion and manoeuvring capability at service speeds of 8–12 km/h. Together with the optimised hull geometry, this configuration ensures low hydrodynamic resistance and predictable energy consumption suitable for corridor-based logistics. The internal arrangement of the vessel follows a clean and functional layout, with the central cargo hold extending over most of the vessel's length. The upper deck is intentionally left unobstructed to facilitate container handling by gantry cranes or reach stackers, enabling seamless integration into existing terminal operations. Reinforced coamings and a straightforward deck structure ensure that the vessel remains compatible with standard container-handling procedures despite its autonomous design intent.

A key feature of the AUTOFLEX vessel is the installation of a standard 20-ft ZESpack on the poop deck (see Figure 1-3).

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Figure 1-3: AUTOFLEX Inland Container Vessel with ZESpack on the poop deck

This arrangement ensuring that the ZESpack remains outside the cargo area while maintaining full accessibility for emergency response, maintenance and automated swapping operations.

Overall, the vessel has been developed considering the necessary Stow&Charge terminal infrastructure (see chapter 6). Its operational profile, defined sailing speeds, modular energy storage and simplified handling interfaces support an integrated approach to energy distribution along the identified waterway corridors. This builds the technical foundation for the energy demand calculations, route analyses and terminal assessments developed within chapter 6 .

1.4.3. AUTOFLEX VESSEL ENERGY CONSUMPTION AND POSSIBLE SAILING RANGE

The overall energy consumption of the vessel is determined by the hydrodynamic characteristics of the hull based on model test investigations carried out by DST and documented in Deliverable D4.3 (see Figure 1-4).

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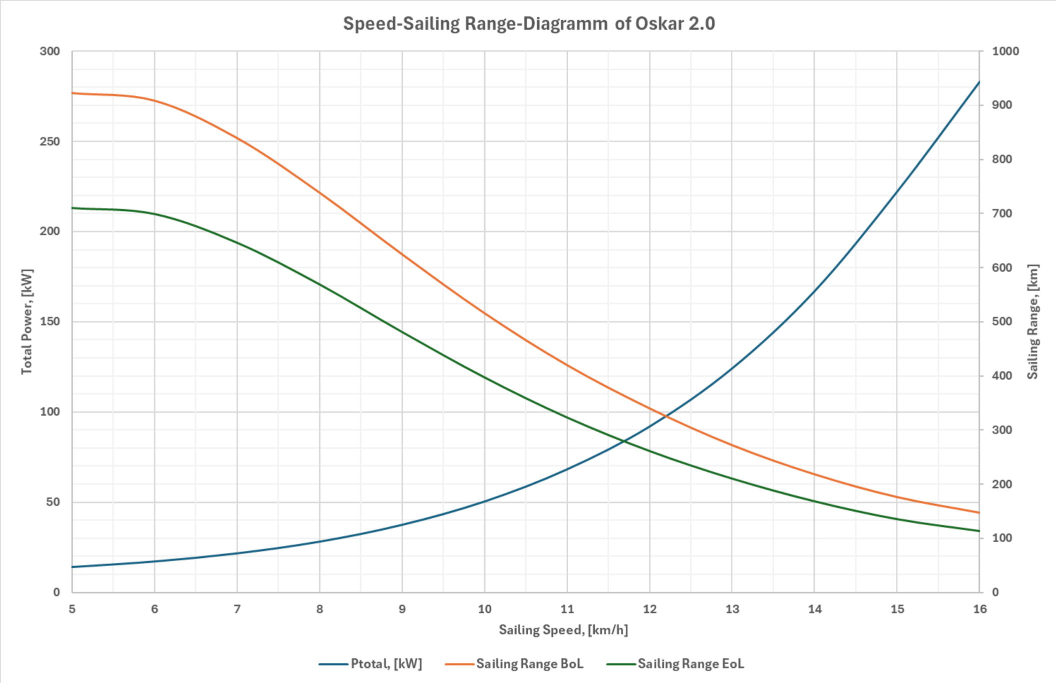

Figure 1-4: Speed-Power diagram of AUTOFLEX vessel

Preliminary resistance and power calculations demonstrate that the required propulsive power remains modest across the relevant operational speed range. At 7 km/h, the total required power is approximately 21.7 kW, increasing to 28.1 kW at 8 km/h. At 10 km/h, which marks as a sensible reference point for sensitivity analysis, the total energy demand rises to roughly 50.4 kW. The power values include a constant service load of 10 kW, representing the electrical demand of onboard systems such as navigation equipment, communication systems, automation hardware and auxiliary converters. Since the vessel is going to operate most likely within the range of 8-10 km/h, its daily energy demand remains well within the capacity limits of a single ZESpack.

From an operational perspective, the combination of moderate propulsion power requirements and substantial onboard energy capacity results in sailing ranges that are well aligned with corridor-based inland waterway operations. At an energy-efficient operational speed of 7 km/h, the vessel can cover approximately 840 km under BoL battery conditions and around 646 km under EoL conditions using a single ZESpack. At 8 km/h, the achievable range amounts to roughly 739 km (BoL) and 569 km (EoL). At the defined service speed of 10 km/h, the operational range remains significant, reaching approximately 516 km under BoL conditions and 397 km under EoL conditions (see Table 1-1)[1].

[1] BoL and EoL battery parameters are explained in chapter 6.3.3

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Table 1-1: Analysis of possible sailing distance depending on sailing speed and power estimations

Speed [km/h]	P total [kW]	Endurance BoL [h]	Sailing range BoL [km]	Endurance EoL [h]	Sailing range EoL [km]
5	14	185	923	142	710
6	17	152	909	117	699
7	22	120	840	92	646
8	28	92	739	71	569
9	37	69	625	53	481
10	50	52	516	40	397
11	68	38	420	29	323
12	92	28	340	22	261
13	124	21	272	16	210
14	167	16	218	12	168
15	222	12	176	9	135
16	283	9	147	7	113

These values are derived for calm water conditions. A conservative canal margin of 5% has been applied to the total propulsion power demand to account for typical inland operational influences such as shallow-water effects, wind loads, etc. While the results represent idealized performance estimates, they provide a robust indication that the vessel can reliably service the targeted inland corridors with a single ZESpack, particularly when intermediate charging or automated battery swapping is available at strategically located Stow & Charge terminals.

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2 AUTOFLEX USE CASES

The motivation for creating the AUTOFLEX project was to create innovations that may contribute to the EU ambition of shifting substantial parts of road freight to waterborne transport [7]. Achieving this ambition requires targeting the major freight flows of Europe and investigating how they could be shifted from road to water. Road freight flow intensity relates to population and industry density; where there are many people and/or factories there is also a high consumption of goods. Following this logic, the AUTOFLEX project defined Use Case 1 as presented in section 2.1 .

Another important EU ambition is to transition to green energy, as outlined by the European Green Deal [7]. To achieve this transition in the transport sector, it will be necessary to have production and supply of green energy in central transport system nodes. The AUTOFLEX project Use Case 2 (section 2.2) was defined to study this problem. In addition, Use Case 2 was formed to be the basis for the project demonstration of autonomous navigation.

2.1 USE CASE 1: THE CONGESTED ROADS IN THE NETHERLANDS

The Netherlands ranks among the most densely populated countries in Europe, with urban regions such as Rotterdam, The Hague, Utrecht, and Amsterdam exhibiting particularly high population densities. These cities are interconnected by the nation's most heavily trafficked motorways. Notably, the A13 corridor between The Hague and Rotterdam records an average daily traffic volume of approximately 140,000 vehicles, making it the busiest motorway in the country. Following closely are the A10 (encircling Amsterdam) and the A12 (connecting Utrecht and The Hague). At the provincial level, Utrecht experiences the highest traffic intensity, followed by Zuid-Holland (which includes Rotterdam and The Hague) and Noord-Holland (encompassing Amsterdam, IJmuiden, and Haarlem).

This region also forms a critical segment of the Trans-European Transport Network (TEN-T), specifically the North Sea–Baltic corridor, which traverses the area via the A13 and A4 motorways and the major inland waterways connecting Rotterdam, Utrecht, and Amsterdam. Running in parallel to these congested highways is a dense network of minor inland waterways extending into urban centres. Three principal north-south routes—referred to as “veins”—can be identified within this network. The eastern vein comprises CEMT class VI canals linking Rotterdam, Utrecht, Amsterdam, and IJmuiden. The central vein includes CEMT classes V through II connecting Rotterdam and Amsterdam, while the western vein consists of CEMT class II canals serving Rotterdam, Delft, The Hague, Leiden, Haarlem, and IJmuiden. Additional branches connect these main arteries and extend into cities, with classifications ranging from CEMT III to I. Presently, substantial cargo traffic is confined primarily to the eastern vein, whereas the western routes are dominated by recreational vessels and lack commercial freight activity.

2.2 USE CASE 2: THE GHENT ZERO-EMISSION TERMINAL

The regions surrounding Rotterdam, Antwerp, and Ghent serve as critical nodes in European freight logistics, with substantial volumes of cargo transiting through these corridors. These areas are also extensively covered by major inland waterways, which already support a significant share of freight transport. Nonetheless, opportunities remain to further increase

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the modal share of waterborne transport. Presently, inland waterway freight in this region is predominantly handled by large, fossil fuel-powered vessels (CEMT classes IV–VI) serving major inland ports. Transitioning to zero-emission vessels is essential for mitigating the environmental impact of this transport activity. Furthermore, integrating such vessels into local and regional distribution networks—as explored in Use Case 1 (UC1)—is necessary to reduce reliance on road-based transhipment and last-mile delivery. A related challenge concerns the mismatch between renewable energy supply and demand, compounded by significant fluctuations in grid load, which creates additional barriers to the electrification of transport systems.

Use Case 2 (UC2) aims to address these challenges through the development and demonstration of the Stow&Charge concept—multifunctional hubs designed to enable both renewable energy supply and efficient multimodal cargo transhipment. These hubs will serve as key infrastructure within a zero-emission transport system, supplying energy to electric vessels and vehicles while facilitating intermodal cargo transfers. The strategic placement of Stow&Charge hubs and their integration into the broader transport network will be investigated, with a focus on energy grid services and load balancing in coordination with UC1.

Additionally, the UC2 is the basis for the project demonstrator, which is not in scope for this report.

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3 BACKGROUND

The innovations presented in this deliverable are targeting three main barriers to shifting freight flows from road to inland waterways. These barriers were discussed in detail in the paper [8], which is a result from the work within AUTOFLEX WP3. The following sections will present a summary of the insights gained through the literature review of [8]. The literature review approached the problem of decarbonising shipping and logistics through the "5-lever decarbonisation framework" [9], from which it focused on freight demands (further concretised as freight concentration), zero-emission energy, and asset utilisation.

3.1 MODAL SHIFT TOWARDS ROAD TRANSPORT: ECONOMIES OF SCALE, CARGO CENTRALISATION AND THE MARGINALISATION OF SMALL PORTS

The first part of the literature review of [8] investigated how economies of scale has led to cargo centralisation and a shift towards road transport. The first observation made in [8] was that the long-term trend of pursuing lower transport cost per unit, has led to increasingly larger ships. These "mega ships" depends on high utilisation to be viable, i.e., to be cost-efficient. This creates an economic pressure for filling the mega ships, which in turn has led to strategic alliances between carriers, accounting for roughly 90 percent of global TEU, as no single carrier could meet customer demands and fill the mega ships alone. A consequence of this is reduced market diversity, with potential negative impacts on competition and marginalisation of smaller actors.

A second observation made in [8] was that the mega ships has led to a cargo concentration to a limited set of global mega ports. Only ports with sufficient financial capacity, and space, has been able to keep up with the heavy investments needed to provide the required infrastructure and services to support the mega ships. Another cause of the cargo concentration was found to be related to the high operational costs of the mega ships, leading to a need to keep the number of port calls at a minimum. This further marginalises smaller ports and regions, omitting them from their routes, even if they could accommodate port calls for the mega ships. The result is cargo and shipping route concentration, creating a systemic dependency to a few mega ports.

The third observation made in [8] was that small-to-medium-sized ports (SMPs), such as inland and regional terminals, struggles to remain viable in this context due to insufficient financial resources. This leads to SMPs being marginalised, and as SMPs disappear, waterborne alternatives reduce, and mega ports relies increasingly on road transport for their connection to hinterland. Which, in turn, leads to a modal shift away from inland waterways. The result is a negative spiral where the infrastructural gap needed to be closed by SMPs to stay competitive increases as the upgrades stays out of reach.

The conclusion drawn in [8] is that these observations are structural barriers undermining European modal shift ambitions. The proposed solution is to reintegrate SMPs through innovative terminal concepts that offer scalable and adaptable solutions that can revitalise SMPs, especially along underutilised inland corridors. The AUTOFLEX project has researched such solutions and developed a concept that is presented in chapter 5 .

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3.2 FROM SINGLE TO DUAL ROLES: PORTS AS TRANSHIPMENT AND ENERGY HUBS ENABLING RENEWABLE MODAL SHIFT

The second part of the literature review of [8] investigated the role of ports in transitioning to renewable energy inland waterway transport, while supporting the modal shift. The first observation made in [8] was that shipowners will face barriers to transition to new fuels if ports are not proactively involved to provide infrastructure and supply, and facilitate operational and regulatory conditions. Hence, ports were considered crucial enablers in facilitating progress towards emission free transport across the supply chain.

The second observation made in [8] was that ports have evolved from being mostly public entities to quasi-private actors. This also means that they have to some extent shifted focus from promoting regional development and providing accessible infrastructure, to competing to provide their commercial services. Furthermore, ports are no longer just enablers of trade but are active participants providing energy (including renewable energy) and transhipment and influences how sipping networks are formed. Ports are hence becoming business hubs offering services to support the development of itself and economic activity in its region. This has also led to the idea of ports as energy hubs that can produce, store and distribute renewable energy. In fact, ports are positioning themselves as renewable energy hubs to gain a competitive advantage. This includes being a testbed for sustainable technologies and operations.

The third observation made in [8] was that ports face a dilemma when transitioning to renewable energy. Renewable fuels come in many variants, with no clear winner(s) to date. Hence, ports must choose between specialising in a specific type of renewable fuel or invest in several options. The former choice reduces the require investment at the cost of limiting the commercial cooperation with some ship operators, while the latter comes at the cost of high investments and possible port inefficiencies. This dilemma is magnified by the chicken-and-egg relation between ports and ship owners; both relies on the other to operationalise new fuels.

The fourth and final observation made in [8] was that SMPs face additional challenges in the transition to logistics and energy hubs. As they have lower trade volumes and weaker financial muscles, they lack the means to invest in renewable energy for their own operations, and for supply to ships and other vehicles. Hence, SMPs are trailing behind the mega ports when it comes to transitioning to renewable energy. Another challenge is that SMPs often share resources such as bunkering facilities and energy grids with nearby industry, making their transition to renewable energy dependent on other stakeholders, preventing SMPs from making independent decisions. Some SMPs have increased their cooperation with larger ports to overcome these barriers, which might also benefit regional industries on inland waterways.

The conclusion drawn in [8] is that the sector is being reshaped by ports transforming into energy and logistics hubs. And that this is a determining factor for decarbonising supply chains. However, SMPs are trailing behind in the transition to renewable energy, which is a challenge for regional economic equity. Furthermore, it is also a major challenge for revitalising European IWT, a key to achieving the climate and modal shift goals. The solution proposed in [8] is to develop modular and scalable concepts that combine energy production, storage and delivery, with cargo handling. The AUTOFLEX project has researched such a solution, called the Stow&Charge, which is presented in chapter 6 .

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3.3 SYSTEMIC TRANSPORT WASTE FROM SUBOPTIMAL UTILISATION OF TRANSPORT CAPACITIES

The third and final part of the literature review of [8] investigated transport waste from suboptimal utilisation of cargo units and transport vehicles. The first observation that was made was that a significant part of European road transport does not exploit the transport capacity of the vehicle, nor the cargo unit. By considering the weight capacity of the average vehicle, the cargo unit capacity, the average load for non-empty trips, and the number of empty trips, the average system wide utilization is estimated at 59 percent. It was noted that some cargo has high volume compared to weight, making it impossible to exploit the weight capacity of trucks or containers fully, leading to this estimate being inaccurate. Nevertheless, it highlights that there are significant inefficiencies in European freight transport.

The second observation made in [8] was that underutilisation is also a problem in waterborne transport. While accurate estimates are missing, empty container repositioning alone is estimated at 15 to 20 billion USD annually for global shipping. The most significant cause of this is the imbalance in traffic flows. In addition, partially filled containers, or transport units, known as less-than-container load (LCL), is also an issue in waterborne transport.

The third observation made in [8] was that improved consolidation, i. e., increased utilisation, for both ships and transport units (trailers and containers), is needed to mitigate transport waste. Which in turn would reduce environmental impact of supply chains. However, this is challenging because unlike road transport, which can adapt better to cargo flow imbalances, waterborne transport depends on high and balanced cargo volumes to ensure high utilisation. Achieving this implies strategic placement of consolidation centres in the hinterland, where large cargo flows converge. Furthermore, containers eligible for cargo consolidation would have to be LCLs, and transhipment costs would have to be kept to a minimum. This is challenging due to the poor coordination between IWT vessel and deep-sea terminal operators today, which implies that structural changes are needed. In urban logistics, municipalities use financial and regulatory measures at times to incentivize greener logistics through consolidation centres, yet they remain poorly implemented.

The fourth and final observation made in [8] was that there are also some drawbacks to consolidated transport. It complicates just-in-time (JIT) deliveries, delivery speed and reliability might rule out service types such as “same-day delivery”, and differences in value and time-criticality might make consolidation of homogenous goods more feasible than for heterogeneous flows of goods.

The conclusion drawn in [8] was that low utilisation of transport capacities causes increased emissions and costs. While cargo consolidation is important for sustainable transport, it often fails due to infrastructural, temporal, and commercial challenges. The solution proposed in [8] was that new consolidation concepts enabling multiple transport costumers to share segmented containers at the point of loading and unloading needs to be developed. The AUTOFLEX project has researched and developed such a concept, and the results are presented in chapter 7

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4 MODAL SHIFT TARGETS (MSTS)

As discussed in chapter 3 , the overarching objective for this deliverable is to contribute to decarbonization of shipping and logistics, through addressing three areas of the "5-lever decarbonization framework" [9]. The identified approaches were to develop three transport system components. First, a terminal concept that can reintegrate SMPs through offering innovative, scalable and adaptable solutions. The AUTOFLEX project coined this concept the *Temporary Port Terminal* (TPT), envisioned to be a lightweight, relocatable, minimal investment terminal concept that takes advantage of existing infrastructure such as abandoned quays. Secondly, a terminal concept that integrates zero-emission infrastructure and supply with efficient cargo transfer. This is the AUTOFLEX concept *Stow&Charge* (SCH), which is based on modules for energy production, storage and distribution, and for cargo handling, as well as layouts for how such terminals could be constructed. Finally, a mobile distribution concept that can combine transport, distribution and consolidation of part loads. This is the AUTOFLEX *Mobile Distribution Centre* (MDC) concept. Envisioned as a transport unit that incorporates the features of parcel lockers used for distribution and consolidation of parcels in urban environments.

While the high-level conceptual ideas of the TPT, SCH and MDC, were developed during the project establishment phase, it was necessary to study the potential real-life applications to derive design requirements. This to ensure that the innovations are designed to be efficient in their intended applications. The initial problem to solve was hence to identify the opportunity areas where the innovations could have a positive impact on the core problem, namely the climate impact of transport and logistic. As the project approach to this is to utilise waterways that are currently not used for cargo transport to reduce road transport, it was necessary to identify the waterways that, if used, would have the greatest positive impact.

The following sub-sections identifies where inland waterway transport (IWT) services could most effectively absorb road-based freight volumes by identifying areas with potential modal shift volumes with no existing services. This indicates either that existing terminals could be used to shift transport volumes to waterborne modalities or as is more pertinent to this deliverable, that new terminals could be developed – such as innovative terminal concepts like the TPT. The assessment departs from identifying spatial concentrations of external costs as a result of population densities and regional Gross Domestic Product - GDP (A), advances through analysis of road congestion pattens (B), the availability of a potential waterborne alternative to this congestion (C), the gaps in existing IWT services on these waterborne alternatives (D), the potential modal shift customers that could be interested in developing services closing these gaps (E), and, finally, arrives at specific areas where TPT could be deployed to usher an increased modal shift – i.e. the Modal Shift Opportunity Areas (MSOAs) (F). This chapter extends the work within AUTOFLEX WP2 [10].

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4.1 (A) HIGH EXTERNAL COST AREAS (HECA)

High external cost areas are zones where road-based freight transport imposes disproportionate impacts due to congestion. That is, areas with a combined relatively higher population density and economic activity can be expected to have proportionally higher external costs in terms of increased health-related costs from poor air-quality and production-related costs from ineffective manhours spent idling in traffic.

Population distribution and regional GDP patterns of the Netherlands show that the Randstad and the Dutch industrial belt dominate both demographic and economic activity, see Figure 4-1 and Figure 4-2. Specifically, higher population densities can be seen around the larger Dutch cities of Amsterdam, Den Haag, Utrecht, Rotterdam, Haarlem, Tilburg, Eindhoven and Groningen. This means that the Dutch population is predominantly living in the *Randstad*: a Metropolitan Area (MA) which loosely translates to "ring city". It is a polycentric conurbation that has both the largest cities of the country (i.e. Amsterdam, Den Haag, Utrecht and Rotterdam), as well as several medium-sized urban centres (i.e. Almere, Delft, Dordrecht, Gouda, Haarlem, Leiden etc.). Although these cities do not have excessive populations individually, the Randstad MA collectively accounts for over 40 percent of the national population, making it the fourth most populous MA in Europe after Paris, Madrid, and the Rhine-Ruhr area [11], [12]. Figure 4-3 confirms this observation.

In addition to its demographic significance, the Randstad MA contributes roughly half of the Netherlands' national income which underscores its socio-economic role within the country [11], [12]. This is confirmed by Figure 4-2. Specifically, the greater Amsterdam region displays an exceptionally high regional GDP, with ca. 130 billion EUR. This is around 1.5 times as high as for the second and third highest regional GDPs in the Netherlands, namely the greater Utrecht and greater Rotterdam areas with ca. 83 billion and 77 billion EUR respectively. Other areas with noticeable regional GDPs are the greater Eindhoven area (ca. 46 billion) and the greater Den Haag area (ca. 42 billion). In general, as can also be deduced from Figure 4-2, the GDP of the Netherlands seems concentrated particularly in the Randstad MA (Amsterdam, Utrecht, Den Haag, Rotterdam) with the area around Eindhoven following thereafter.

Combining population density with regional GDP leads to the following High External Cost Areas (HECAs), as defined in Table 4-1 and illustrated in Figure 4-3:

Table 4-1: High external cost areas (HECAs)

HECA1	**Greater Amsterdam**: Very high population and very high GDP mean potentially immense external costs in the area in and around Amsterdam.
HECA2	**Greater Utrecht**: High population and high GDP mean potentially high external costs in the area in and around Utrecht (including Amersfoort).
HECA 3	**Greater Rotterdam**: High population and high GDP mean potentially high external costs in the area in and around Rotterdam (including Gouda)
HECA 4	**Greater Den Haag**: Very high population density and above average GDP mean potentially significant external costs in the area in and around Den Haag (including Delft)
HECA 5	**Greater Eindhoven**: Above average population density and above average GDP mean noticeable external costs in the area in and around Eindhoven)

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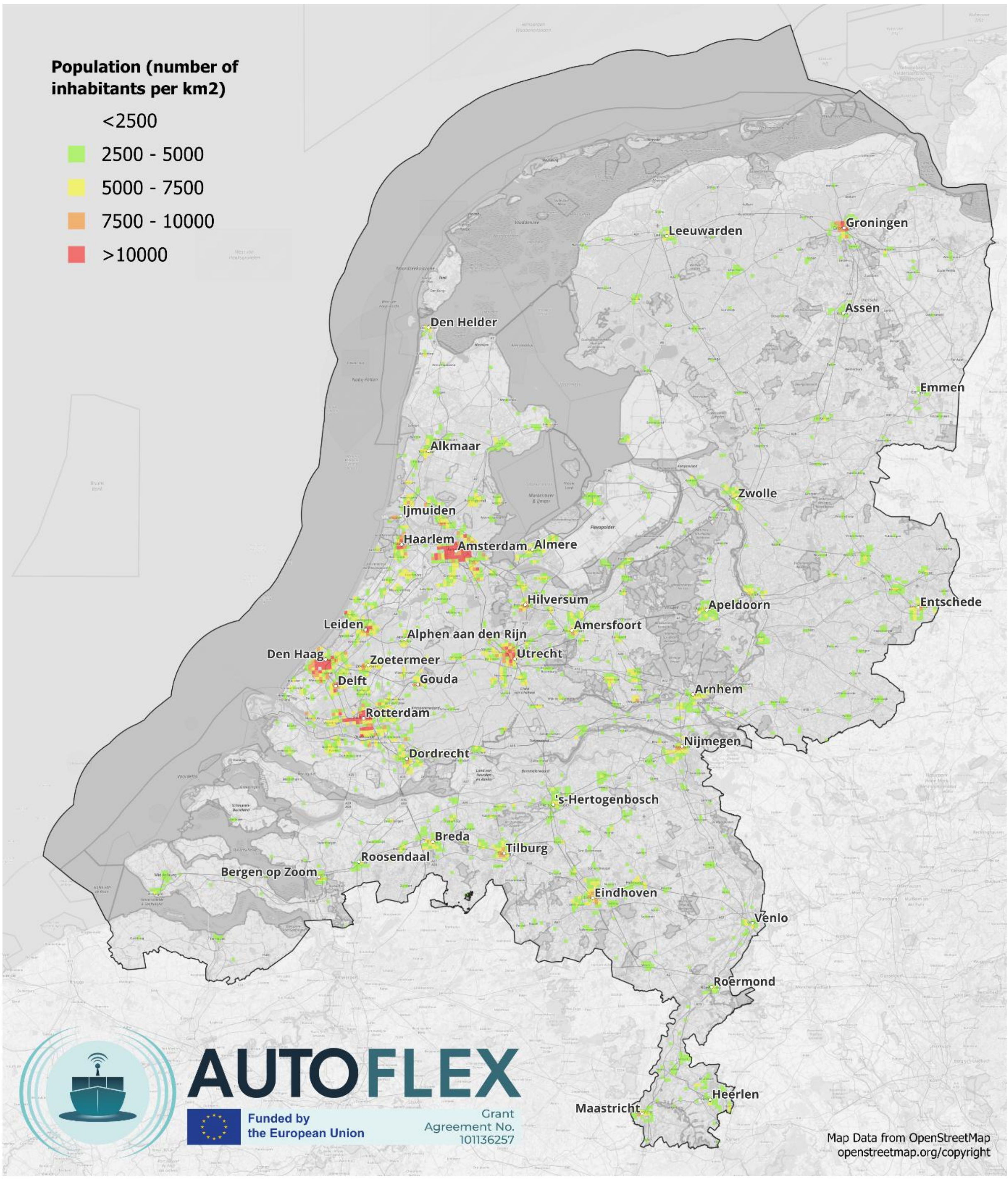

Figure 4-1 Population density of the Netherlands adapted from D2.1 [10]

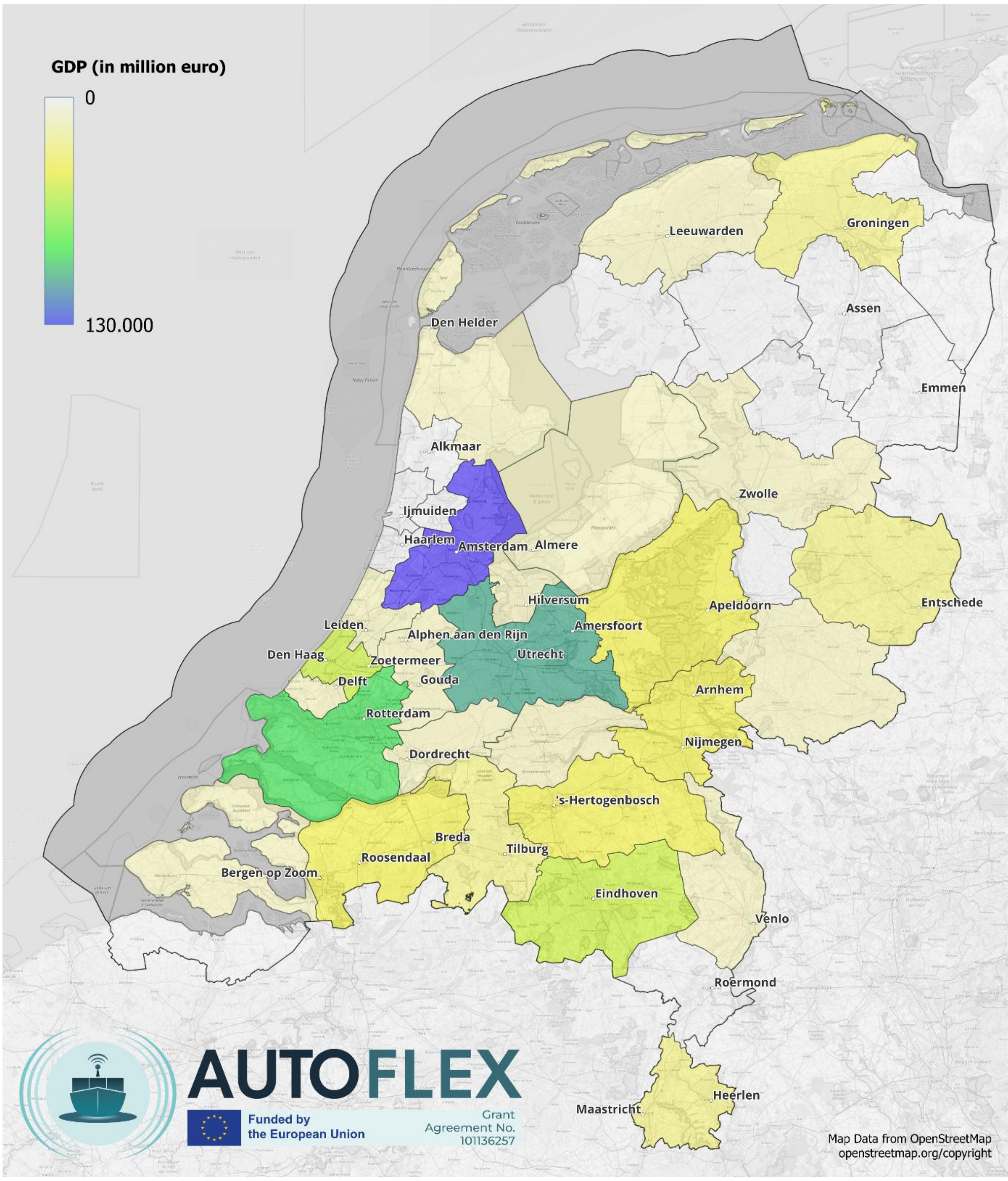

Figure 4-2 Regional GDP of the Netherlands adapted from AUTOFLEX D2.1 [10].

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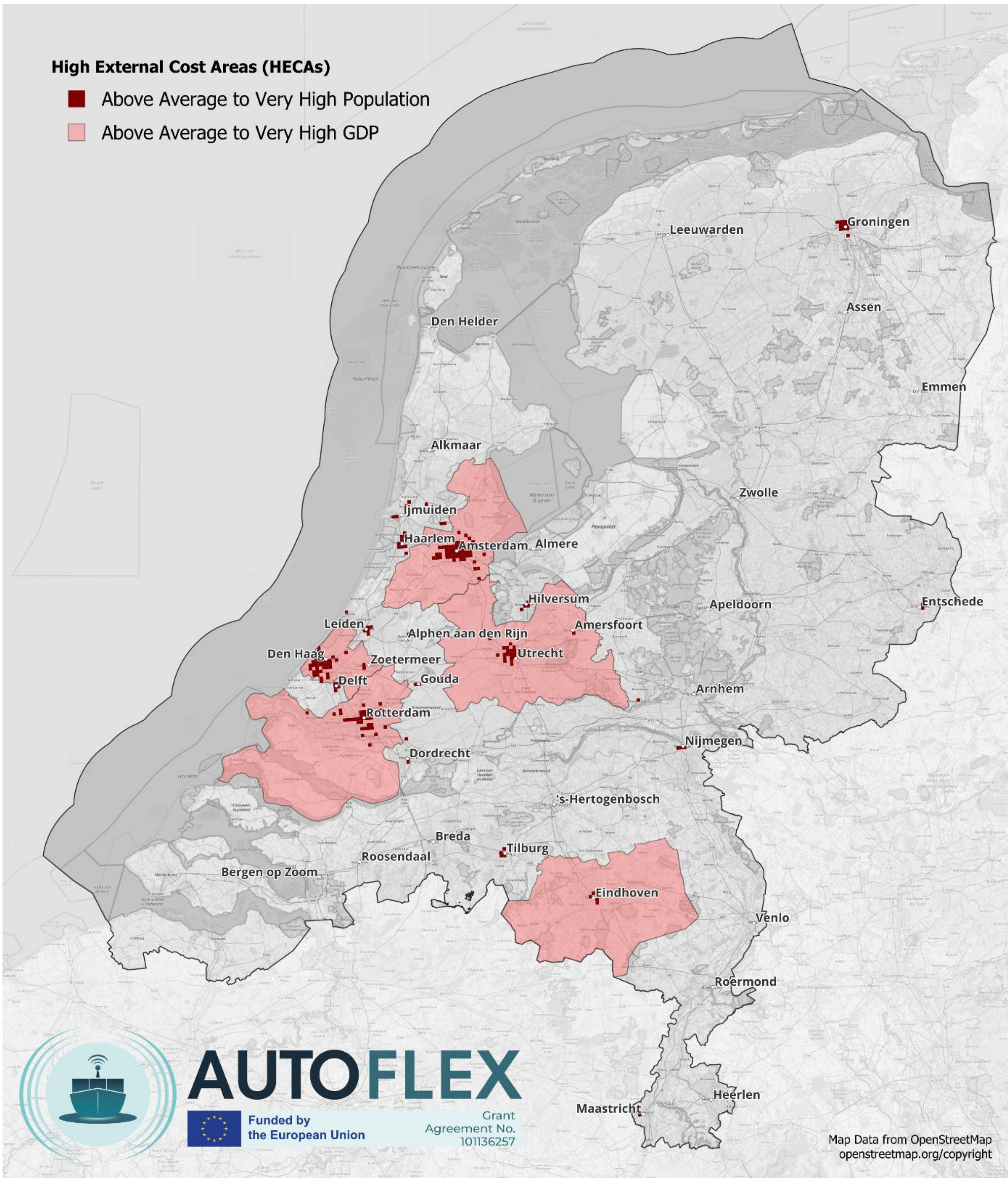

Figure 4-3 High External Cost Areas (HECAs)

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4.2 (B) TRAFFIC-INTENSE CORRIDORS (TIC)

The next step is to identify the road corridors through which the heaviest amount of road congestion, both freight- and citizen-related, can be observed as this will be a direct cause of high external costs. Said differently, for the purposes of this deliverable, high external costs are a direct result of a combined high population density, regional GDP and traffic intensity. To revert these high external costs, modal shift efforts should thus be specifically targeted towards shifting some of the applicable road transport to a waterborne transport modality.

The main high traffic intensity, Figure 4-4, of the Netherlands seems to concentrate around the Randstad MA area – a perhaps not surprising findings given its high population density. Particularly, the main roads between Amsterdam, Utrecht and Rotterdam appears to be significantly challenged by high traffic intensity. High traffic can also be seen on the main road between Rotterdam and, presumably, Antwerp, which passes through Dordrecht and Breda, as well as the main road between Utrecht, 's-Hertogenbosch and Eindhoven. Similarly, high traffic can be seen between Utrecht and Arnhem, presumably extending towards the inland ports on the Rhine-Rhur area, as well as between Eindhoven, Tilburg, Breda, Roosendaal and Bergen op Zoom. Other noticable congestion can be observed in the areas around Alkmaar, Hilversum, Amersfoort, Apeldoorn and in the southeastern most region around Roermond ad Utrecht (including between Utrecht and Eindhoven).

Given that the highest external costs from aggregated road traffic will be seen in the HECAs, the following Traffic Intense Corridors (TICs) have been identified, see Table 4-2 and Figure 4-5.

Table 4-2: Transport Intense Corridors (TICs)

TIC1	**Amsterdam – Den Haag – Rotterdam** One of the worst congested roads in the Netherlands passing through three HECAs, including the most crucial HECA around Amsterdam.
TIC2	**Alkmaar – Amsterdam – Utrecht – Eindhoven** Similar to TIC1, this is very congested corridor, particular between Amsterdam and Utrecht, which passes through the three HECAs of Greater Amsterdam, Greater Utrecht and Greater Eindhoven.
TIC3	**Rotterdam – Utrecht – Arnhem/Nijmegen (towards Rhine-Ruhr)** Similar to TIC1 and TIC2, this is one of the worst congested areas in all of Netherlands and constitutes the last "side" of a severely congested "triangle" within the Randstad MA (between Rotterdam and Utrecht). The corridor further extends towards the Rhine-Ruhr area, passing by Arnhem and can be expected to have a large proposition of heavy freight traffic.
TIC4	**Rotterdam – Breda (towards Antwerp)** A highly congested road corridor between two of the largest seaports of Europe: Rotterdam and Antwerp. This further puts a lot of external costs pressure in cities such as Dordrecht and Breda and the greater Rotterdam HECA.
TIC5	**Eindhoven – Tilburg – Breda – Bergen op Zoom** The last highly congested road corridor, which although less congested than the previous four severely congested arteries, still displays alarmingly high congestion numbers given that it passes through the highly populated Tilburg and Eindhoven cities as well as the HECA5 area around greater Eindhoven. Furthermore, given that a high proportion of this traffic is likely freight transports between the port in Bergen op Zoom and the industrial area of Eindhoven, it may be an opportune corridor for modal shift.

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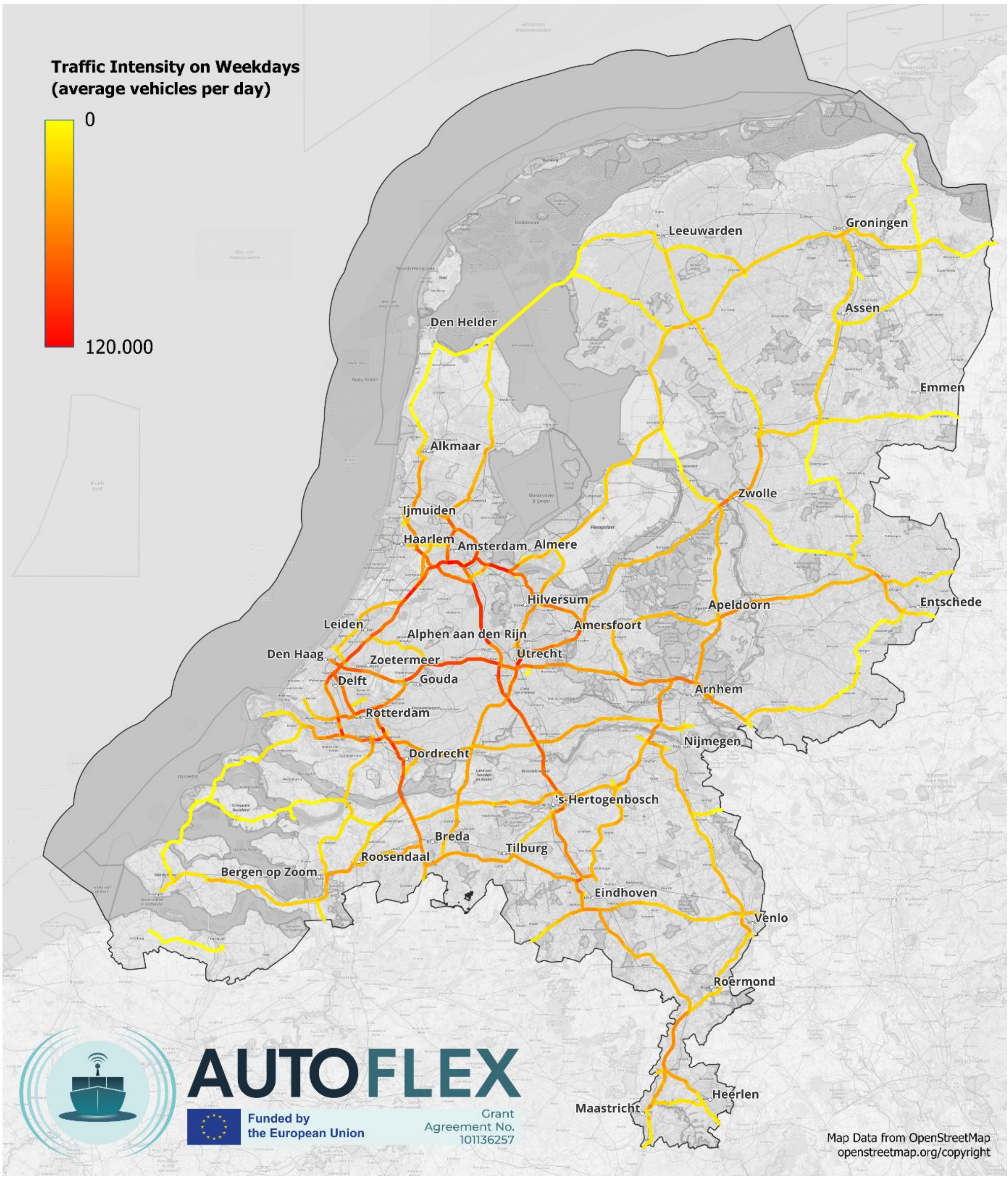

Figure 4-4 Traffic intensity on road (all vehicles)

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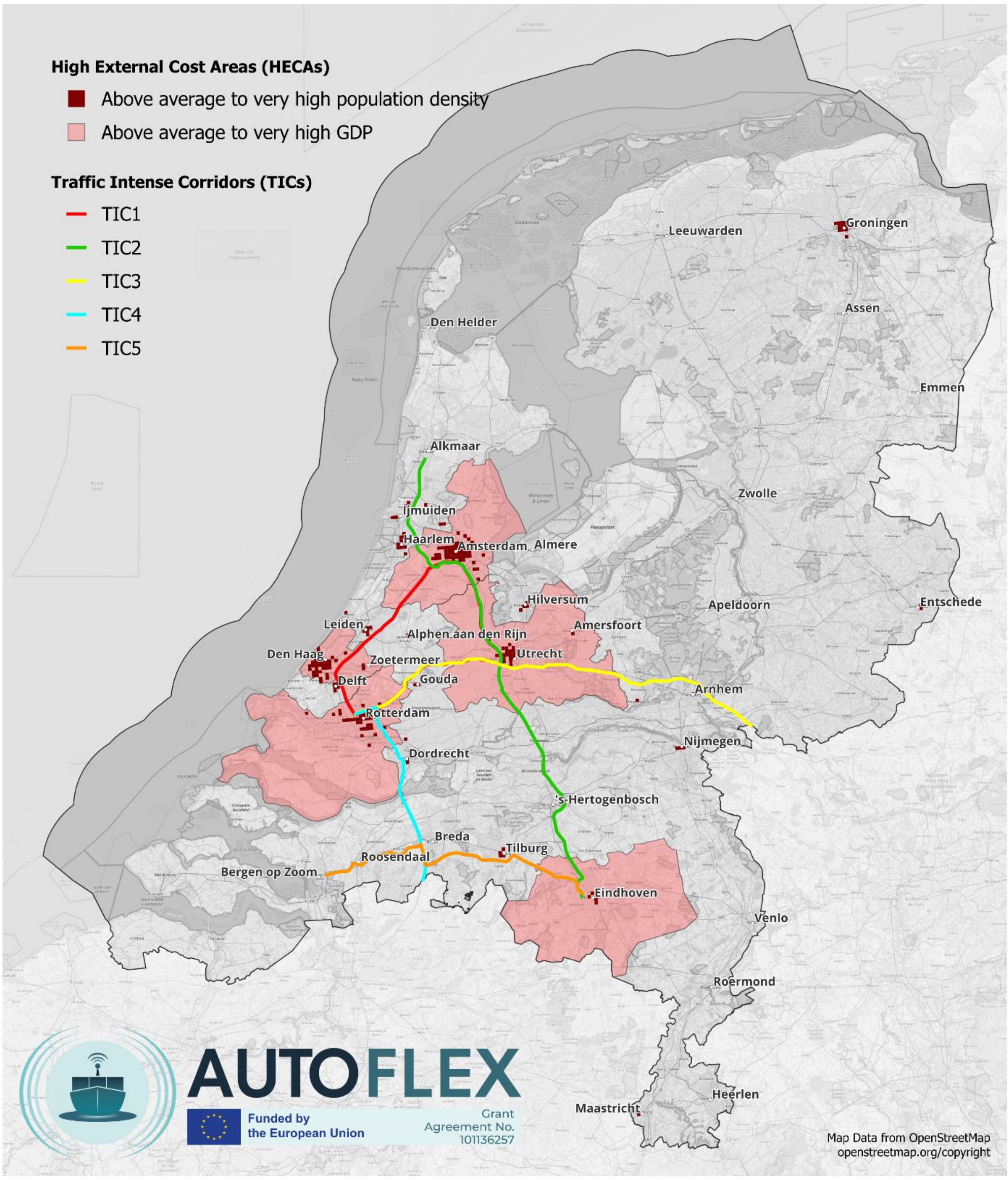

Figure 4-5 Traffic Intense Corridors (TICs)

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4.3 (C) WATERBORNE ALTERNATIVE CORRIDORS (WAC)

In this step, the investigation targets the identification of waterways that could relieve the congested roads indentifeid in the previous step (the TICs). This requiers waterways that are near, preferably paralell, to the TICs, and which provides the same connections as the road network. Fortunately, the Dutch waterways provide a dense and multi-scale canal network (see Figure 4-6). With this extensive coverage of canals throughout the contry, alternative waterborne routs to the strained road systems can be identified. Through matching each traffic-intense corridor (TIC, see Figure 4-5) with existing canals (see Figure 4-6), one or more waterborne alternative corridors, defined as WACs, are identified as given in Table 4-3 and illustrated in Figure 4-7.

Table 4-3: Waterborne Alternative Corridors (WACs)

WAC1	**Provides relief for TIC1.** Consists of two waterborne routes between Amsterdam and Rotterdam: • → Schiphol → Alphen a/d Rijn → Gouda (CEMT III–V) • → Haarlem → Leiden → Den Haag → Delft (CEMT II) (Alphen a/d Rijn and Leiden are connected by a bypass that ensures resilience)
WAC2	**Provides relief for TIC2.** Alkmaar → Amsterdam → Utrecht → ’s-Hertogenbosch → Eindhoven. Varying CEMT classes (II–VI) create segmentation opportunities, where larger vessels feed hubs and smaller vessels distribute into lower-class waterways.
WAC3	**Provides relief for TIC3.** Two high-capacity routes: • Rotterdam → Utrecht → Arnhem • Rotterdam → Dordrecht → Tiel → Nijmegen Both connect to the Rhine-Ruhr hinterland. Domestic potential is modest, but consolidation for seaport access is highly relevant
WAC4	**Provides relief for TIC4.** Rotterdam → Moerdijk → Bergen op Zoom → Antwerp (CEMT VI). Critical for international flows; domestic modal-shift potential is limited but still relevant for intermediate nodes.
WAC5	**Provides relief for TIC5.** Eindhoven → Tilburg → Oosterhout with branches to: • Moerdijk (northbound, CEMT V) • Breda → Roosendaal → Dintelmond → Bergen op Zoom (westbound, CEMT IV–VI) This corridor reaches regions with no or limited existing service despite significant industrial presence.

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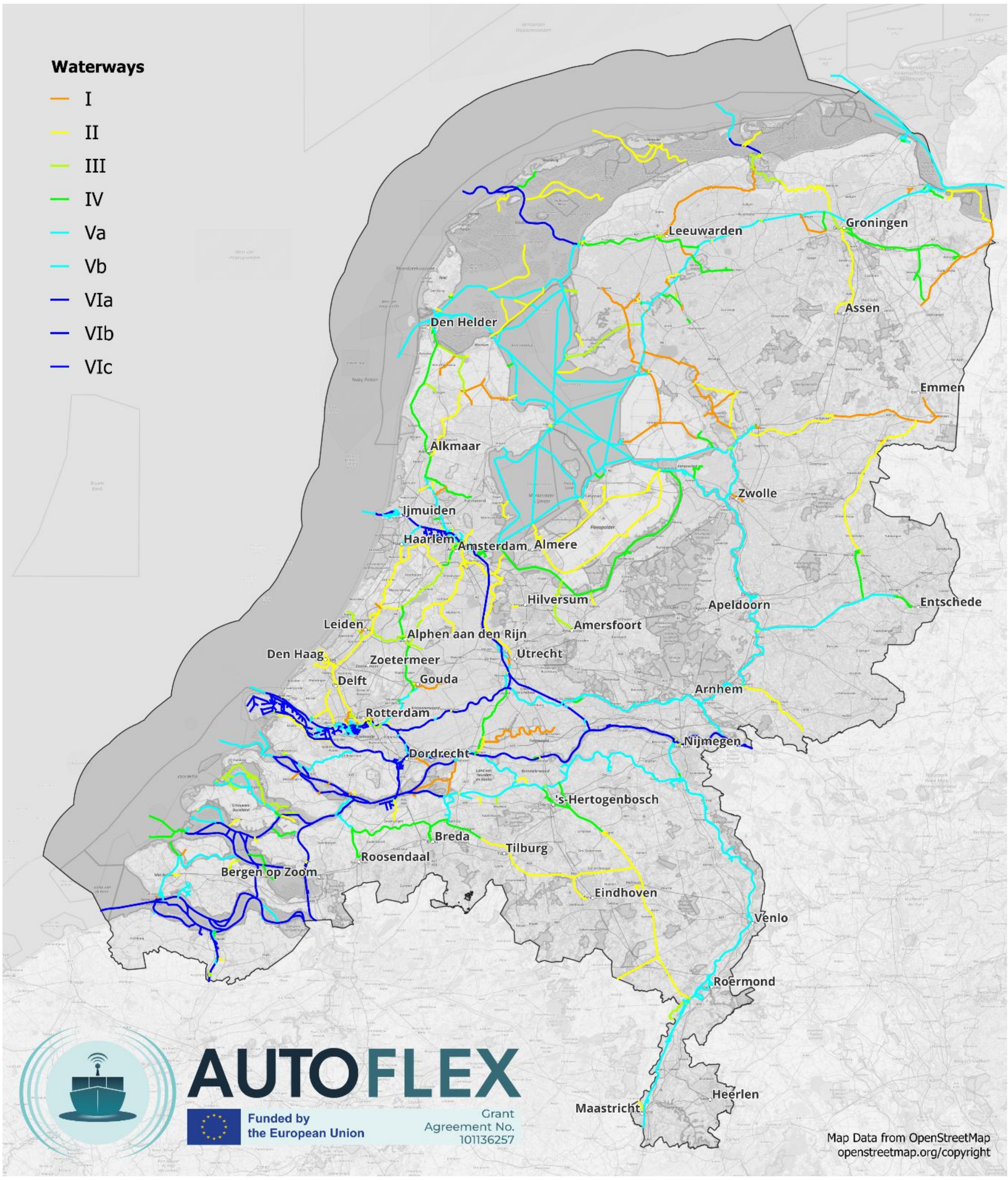

Figure 4-6 Inland waterways (fairways) by CEMT class, adapted from AUTOFLEX D2.1 [10].

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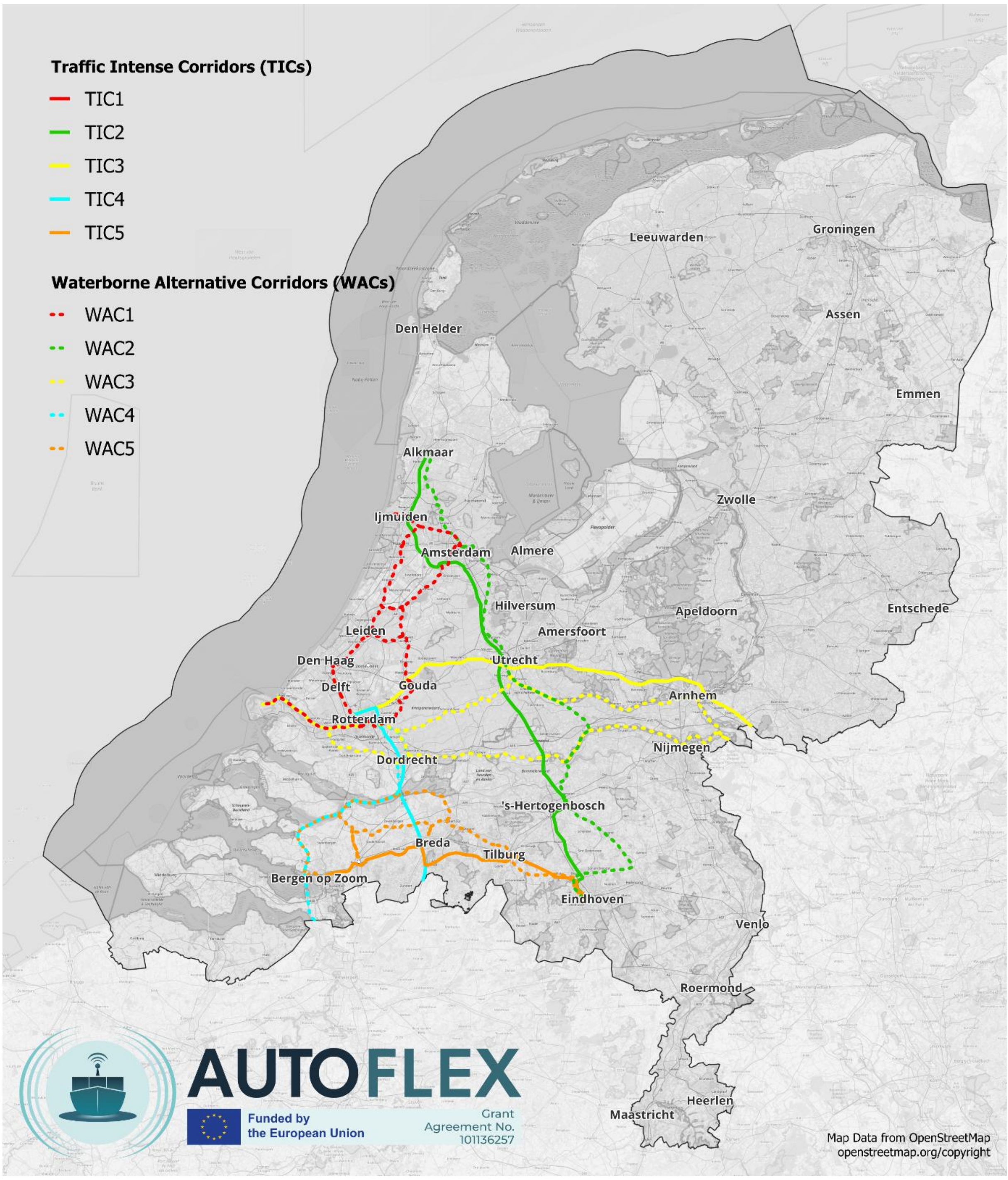

Figure 4-7: Traffic intense corridors (TICs) versus Waterborne Alternative Corridors (WACs)

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4.4 (D) WATERBORNE SERVICE GAPS (WSG)

As many of the waterways of the Netherlands are already used for transportation, the potential for shifting cargo flows from road to waterways lies in establishing transport services on the un- or underutilized waterways. It is therefore necessary to classify the sections of the established WACs into whether they represent a waterborne service gap (WSG) or not – i.e. whether they do not have any existing waterborne container services available (i.e. unutilised) or whether they already so have such service (i.e. utilised). Do however note that although an area may have existing services, and thus do not classify as *unutilised*, this is not to say that the waterways is not in some shape or form *underutilised*. It is beyond the scope of this report to estimate *utilisation* as a relative range (i.e. "overutilied", "underutilised" etc.), by which a clean cut has been made between *utilised* waterways and *unutilised* waterways. Furthermore, it is not within the objective of the AUTOFLEX transport system to necessarily compete with existing IWT services; it is instead to compete with existing trucking services. Consequently, it makes more sense to map where potential roadborne freight volumes are not able to undergo modal shift due to the complete absence of waterborne services today.

Figure 4-8 shows the entire waterway network of the Netherlands, categorised on CEMT classes, and the existing route network. Focusing on the WACs as identified in the previous section, a gap analysis mapping existing IWT services against the WACs, reveals where waterway capacity exists but is not being used for freight transport. Said differently, understanding which sections of which WACs remain unutilised can inform us around which TICs that can be addressed through developing new waterborne services in those WACs (and where in those WACs). This leads to the identification of the waterborne service gaps (WSG) summarized in Table 4-4 per WAC and illustrated in Figure 4-9. Interestingly, across all corridors, unserved waterways are predominantly CEMT II–IV, implying that fleet availability and vessel design will be crucial for exploiting these areas. Therefore, the CEMT II AUTOFLEX vessel has been design with this in mind.

To realise the objective of the AUTOFLEX project, these unserved areas are the waterways where a new AUTOFLEX transport system will have to be established. However, connections to existing services is also important, hence the AUTOFLEX transport system will extend, to some degree, beyond the unserved waterways. The concrete locations that should be considered as candidate nodes in the transport system will be investigated next.

Table 4-4: Unutilised waterways by WAC

WAC1	Largely unutilised except for Rotterdam – Alphen a/d Rijn. The remaining network consists mostly of CEMT II–III waterways, which may require specialised small-vessel operations.
WAC2	Mostly served except: • Alkmaar → Amsterdam (CEMT IV–V) • Veghel → Eindhoven (CEMT II) These ends of the corridor represent primary opportunities.
WAC3	Well served by large-vessel IWT operations. Unutilised potential lies mainly in small-waterway feeders or consolidation services into Rotterdam/Moerdijk.
WAC4	Well served by large-vessel IWT operations. Unutilised potential lies mainly in small-waterway feeders or consolidation services into Rotterdam/Moerdijk.
WAC5	Underutilised except Tilburg → Oosterhout. Eindhoven, Breda, Roosendaal, Dintelmond and Bergen op Zoom show extensive unused potential.

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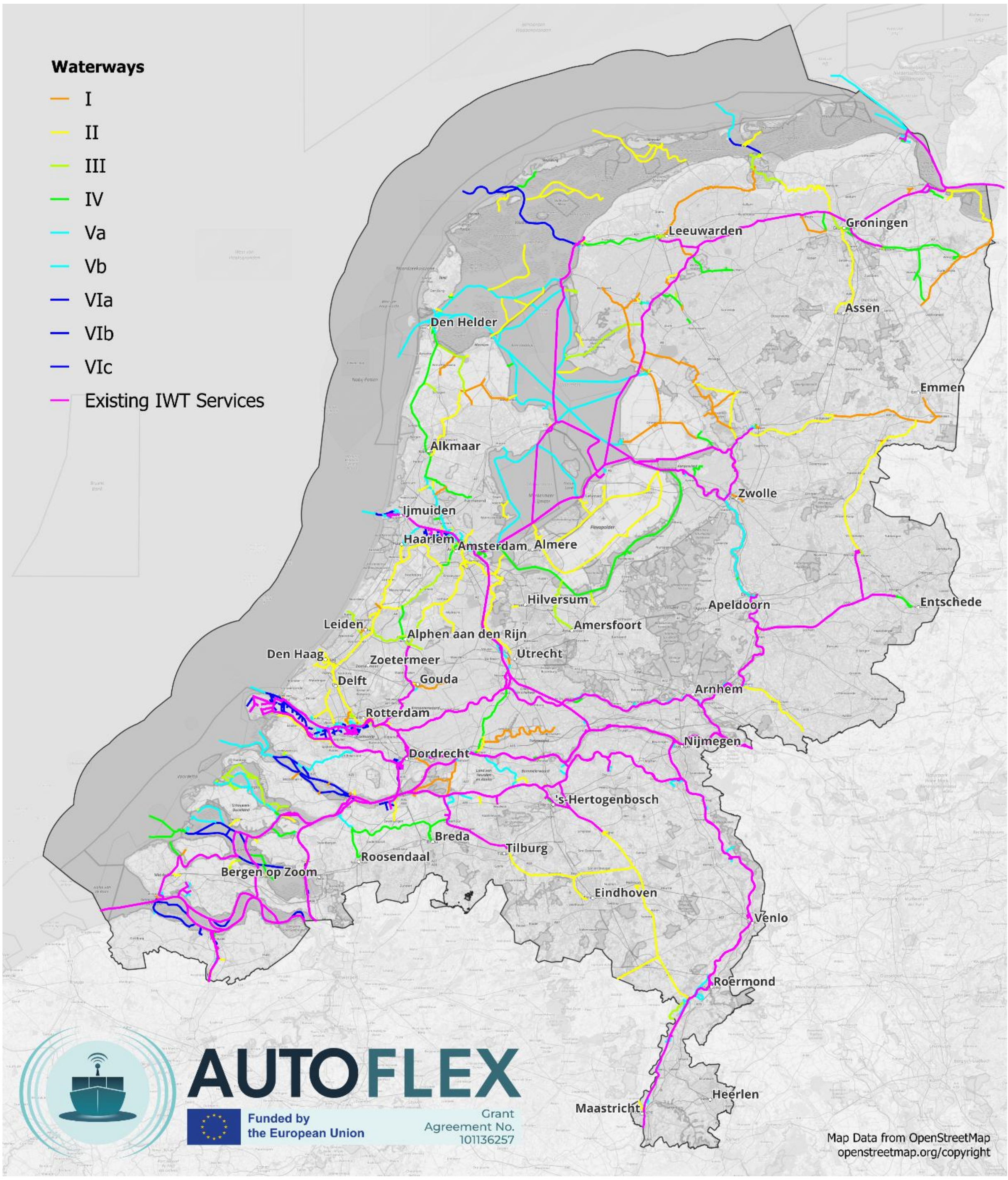

Figure 4-8: Fairways and the existing transport service routes

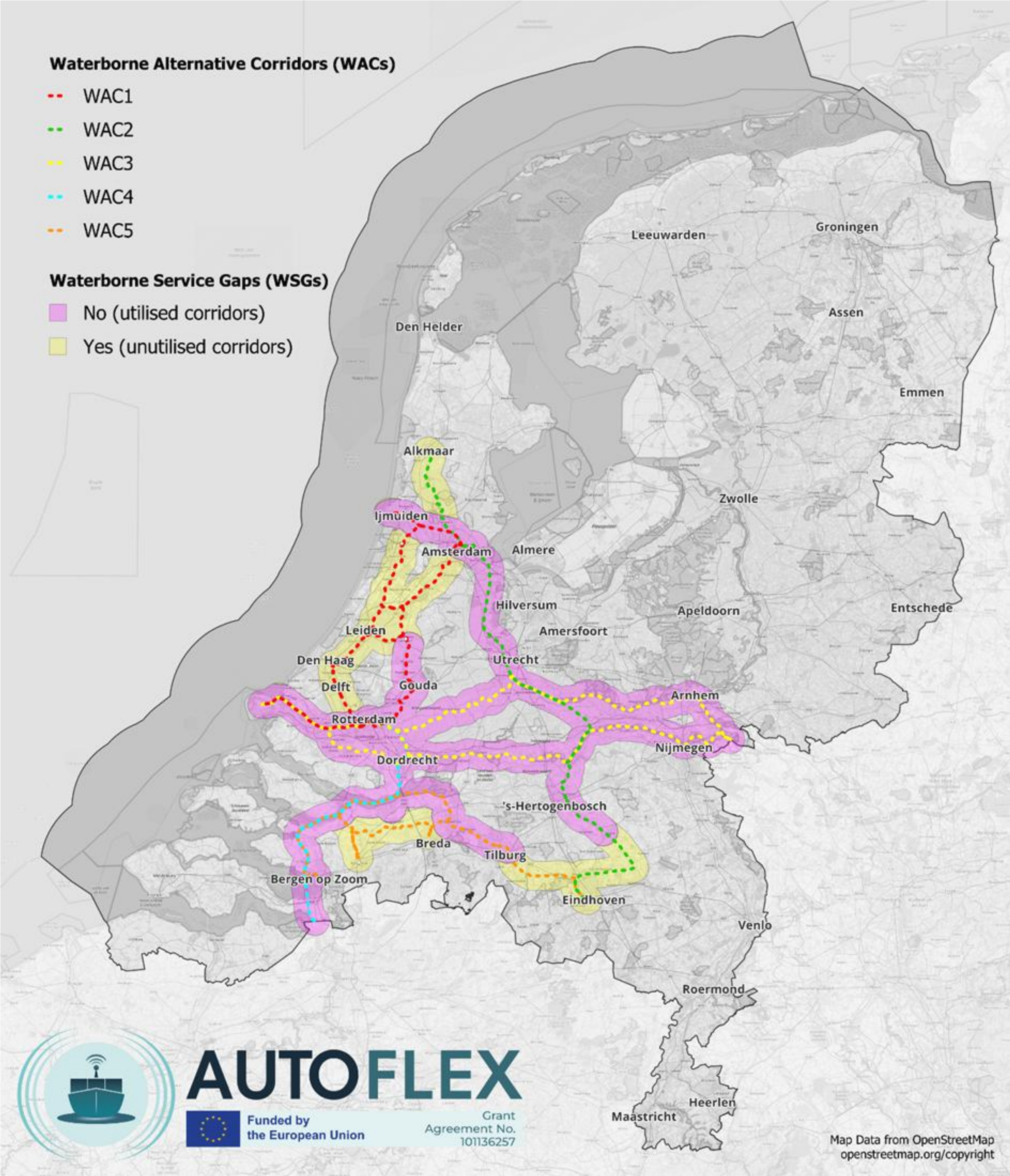

Figure 4-9: WACs and MSFAs

4.5 (E) MODAL SHIFT CANDIDATES (MSC)

As discussed, realising the modal shift implies the establishment of a waterborne transport network reaching into the unserved canals and areas identified in the previous section(s). However, to determine which locations would actually benefit from a connection to this network, it is necessary to investigate the demand for transport. Potential demand for new IWT services depends on clusters of consignees, consignoors and Shippers in a broader sense (e. g., distribution centres and 3PLs etc.) that could realistically consolidate volumes while at the same time relieving congestion issues for citizens. Therefore, land uses, i.e. classifcations that describe how humans use or manage a specific area of land, has been investigated to identify potential actors who may be interested in a waterborne transport modality: that is, the modal shift candidates (MSCs). Thus, Figure 4-10 displays these land use classifications:

- Residential areas in which exacerbated road congestion posits high external costs (vis-à-vis earlier arguments), and are areas with particularly high relevance with regards to establishing a modal shift transhipment service (i.e. a TPT)
- Industrial, retail and warehouse areas which can be considered potential modal shift customers – that is, businesses which may be interested in innovative waterborne transport services such as distribution and consolidation by MDCs, made available through TPTs.
- Farmland and greenhouse areas which potentially also could be considered as modal shift customers. That is, while some food produce may be shipped in dry bulk vessels (for commodities such as grain etc.), other food produce may be shipped in refrigerated containers (for commodities such as fresh vegetables etc.). Thus, although the primary focus of the AUTOFLEX transport system aims at servicing industrial actors, including retail companies and warehouses/distribution centres, there may also be a latent potential of the AUTOFLEX system to service some of these agricultural actors.

The density and size of potential customers and distribution sentres are used to form clusters of Modal Shift Candidates (MSC) as defined in Table 4-5 and illustrated in Figure 4-11.

Table 4-5: Modal Shift Customer (MSC) Clusters

WAC1	MSC clusters around Haarlem, Schiphol, Leiden, Den Haag, and Delft. These clusters lie directly on TIC1's axis and thus represent strong candidates for congestion-relief initiatives.
WAC2	MSC clusters near Amsterdam, Utrecht, 's-Hertogenbosch, Veghel, and Eindhoven. Eindhoven is particularly relevant because it currently lacks IWT services despite being a major industrial node.
WAC3	Fewer MSC clusters, reflective of their international through-flow role. Clusters along these axes tend to rely on road-centric access to the Rhine-Ruhr or Antwerp, making modal shift more challenging.
WAC4	Fewer MSC clusters, reflective of their international through-flow role. Clusters along these axes tend to rely on road-centric access to the Rhine-Ruhr or Antwerp, making modal shift more challenging.
WAC5	MSC clusters near Eindhoven, Tilburg, Oosterhout, Breda, and Bergen op Zoom. This corridor simultaneously experiences road congestion and has underutilised waterways, creating a strong opportunity for introducing new IWT services.

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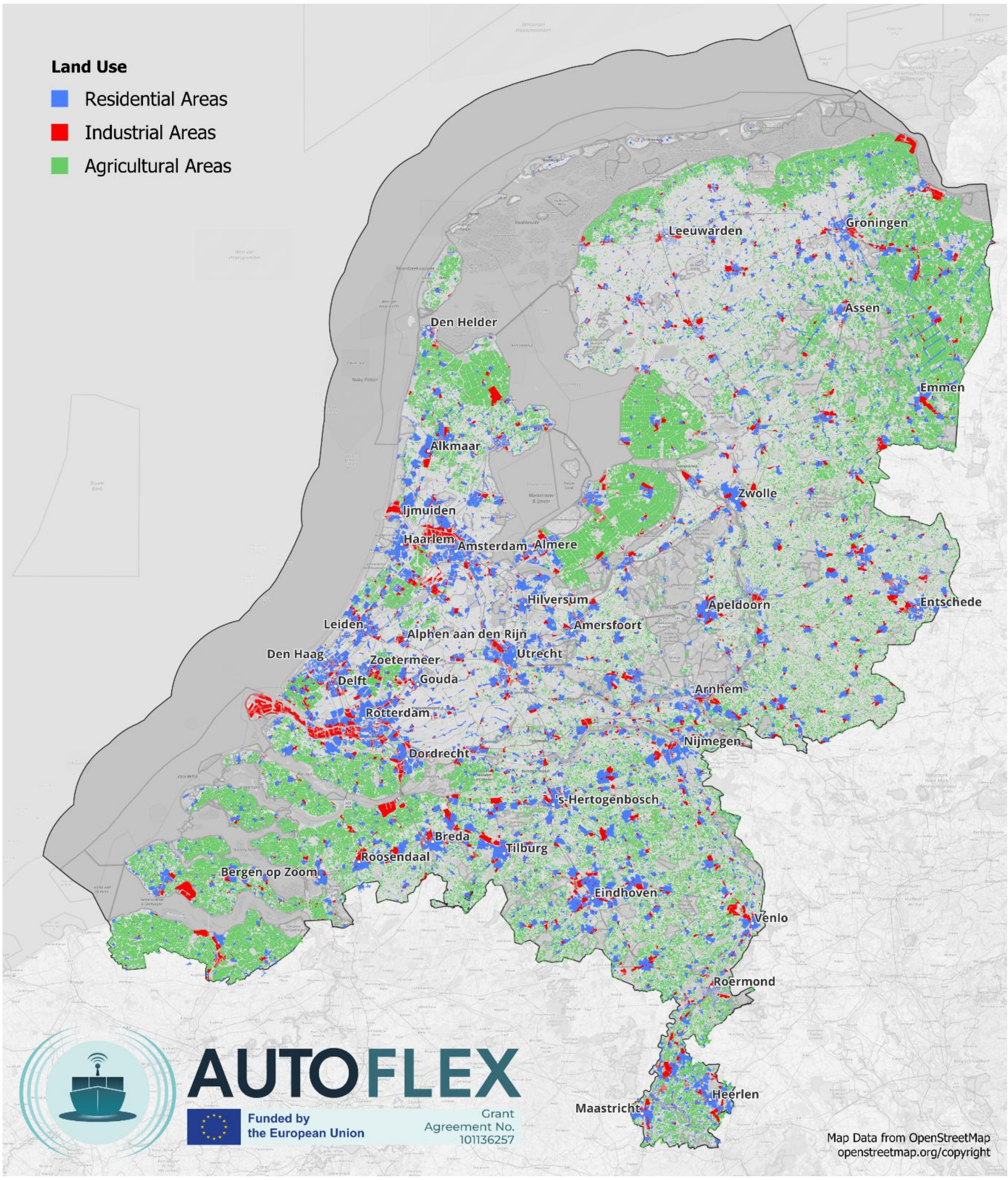

Figure 4-10: Potential transport customers (red shows main AUTOFLEX customer targets)

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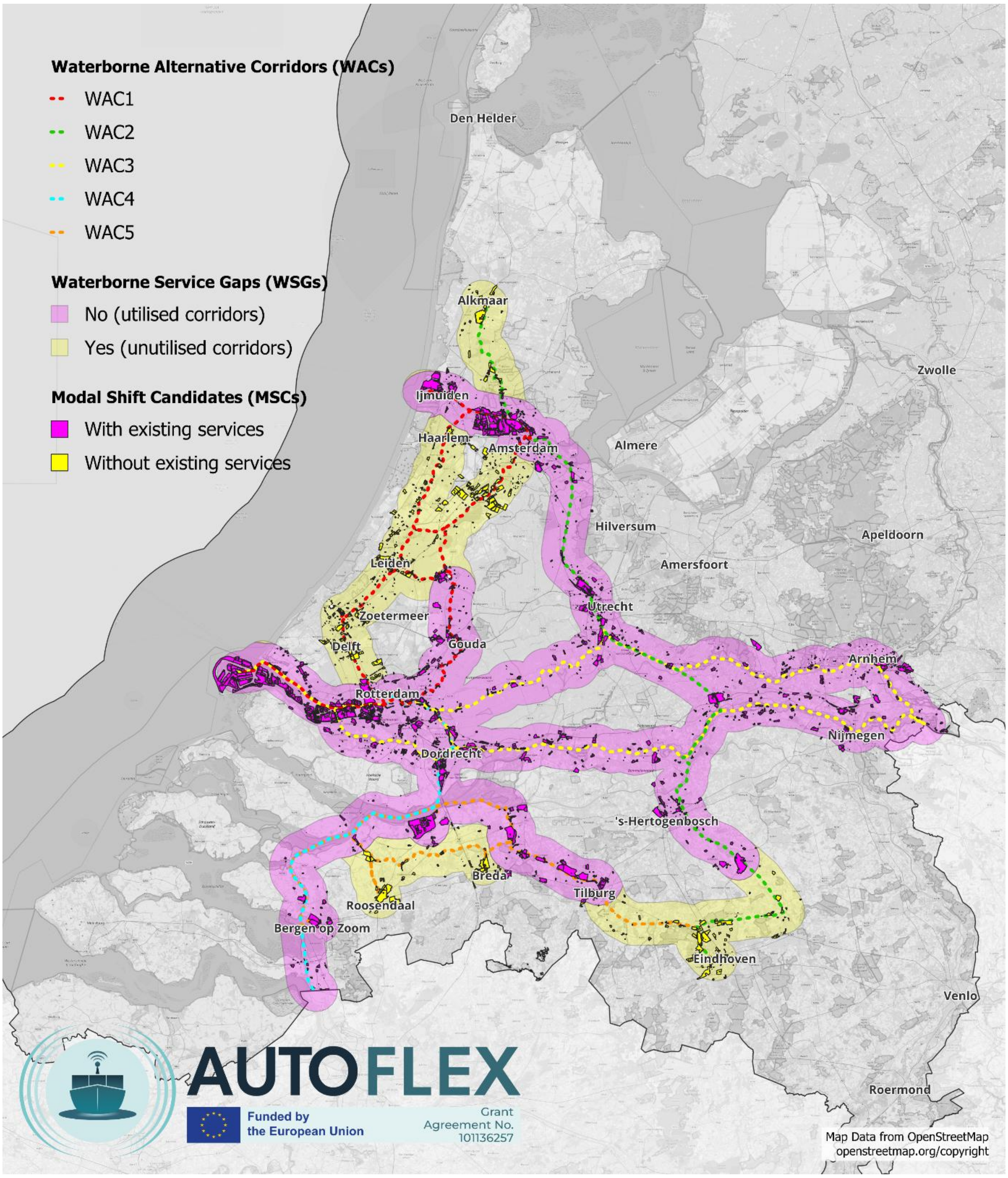

Figure 4-11: WACs, MSFAs and MSTs (the Modal Shift Candidates)

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As can be seen in Figure 4-11, the regions through which the WAC1 and WAC5 (and some of WAC2) transverse have scattered conglomerations of land uses that could potentially be considered clusters of MSCs – particularly on the smaller CEMT II and III waterways on WAC1. Consequently, these two WACs are critical for investigating potential modal shift use cases through the perspectives of Temporary Port Terminals (TPTs) and the Mobile Distribution Centres (MDCs).

Figure 4-12 and Figure 4-13 display a more granular view of these clusters of MSCs along the WAC1 and WAC5 (and WAC2) respectively. What becomes apparent is that specific clusters can be established around the industrial areas outside of the existing service network – i.e. in the so-called Waterborne Service Gaps (WSGs). This leads to the following breakdown of the specific MSC Clusters that will be investigated for the purposes of analysing how a TPT concept (and, to some extent, an MDC concept) could be established within these clusters such that modal shift for unattended transport customers (i.e. the MSCs) could be enabled.

Starting with WAC1, the following MSC Clusters were identified:

MSC Cluster 1	**Haarlem:** Located at the western outskirt of Amsterdam on the western route, and while smaller than the industrial clusters in Delft, Den Haag and Leiden, it may still be a relevant area – potentially also for cargo in the southwestern part of the Amsterdam Metropolitan Area (MA).
MSC Cluster 2	**Schiphol:** A noticeable industrial cluster connected to the primary Dutch airport. This may constitute both an opportunity for imported or exported airborne cargo and for the numerous airport-based commercial actors.
MSC Cluster 3	**Leiden:** Centred almost precisely between Amsterdam and Rotterdam on the western route and displays a somewhat centralised MSOA.
MSC Cluster 4	**Den Haag / Delft:** Noted as a combined MSOA given the continues spread of industrial clusters in the area. However, given its adjacency to the Port of Rotterdam, it may potentially be the case that these industrial sites would make use of Rotterdam-based IWT services. Well served by large-vessel IWT operations. Unutilised potential lies mainly in small-waterway feeders or consolidation services into Rotterdam/Moerdijk.

Continuing with WAC5, the following MSCs were identified:

MSC Cluster 5	**Roosendaal:** A cluster of potential industrial points of interest (PoIs), with a CEMT IV waterway and a rail connection passing right by the industrial area. Thus, potential transport customers could potentially be shifted towards a waterbone and/or railborne transport modality.
MSC Cluster 6	**Breda:** Very similar to Roosendaal – i.e. a cluster of potential industrial PoIs, with an adjacent CEMT IV waterway and rail connection.
MSC Cluster 7	**Eindhoven:** A larger city, hence, a more dispersed cluster of industrial PoIs. With Helmond in near adjacency to the east, one could consider Eindhoven and Helmond one larger industrial area with a lot of potential for modal shift. Eindhoven has both a large rail network passing through its industrial area, as well as a smaller CEMT II waterway.

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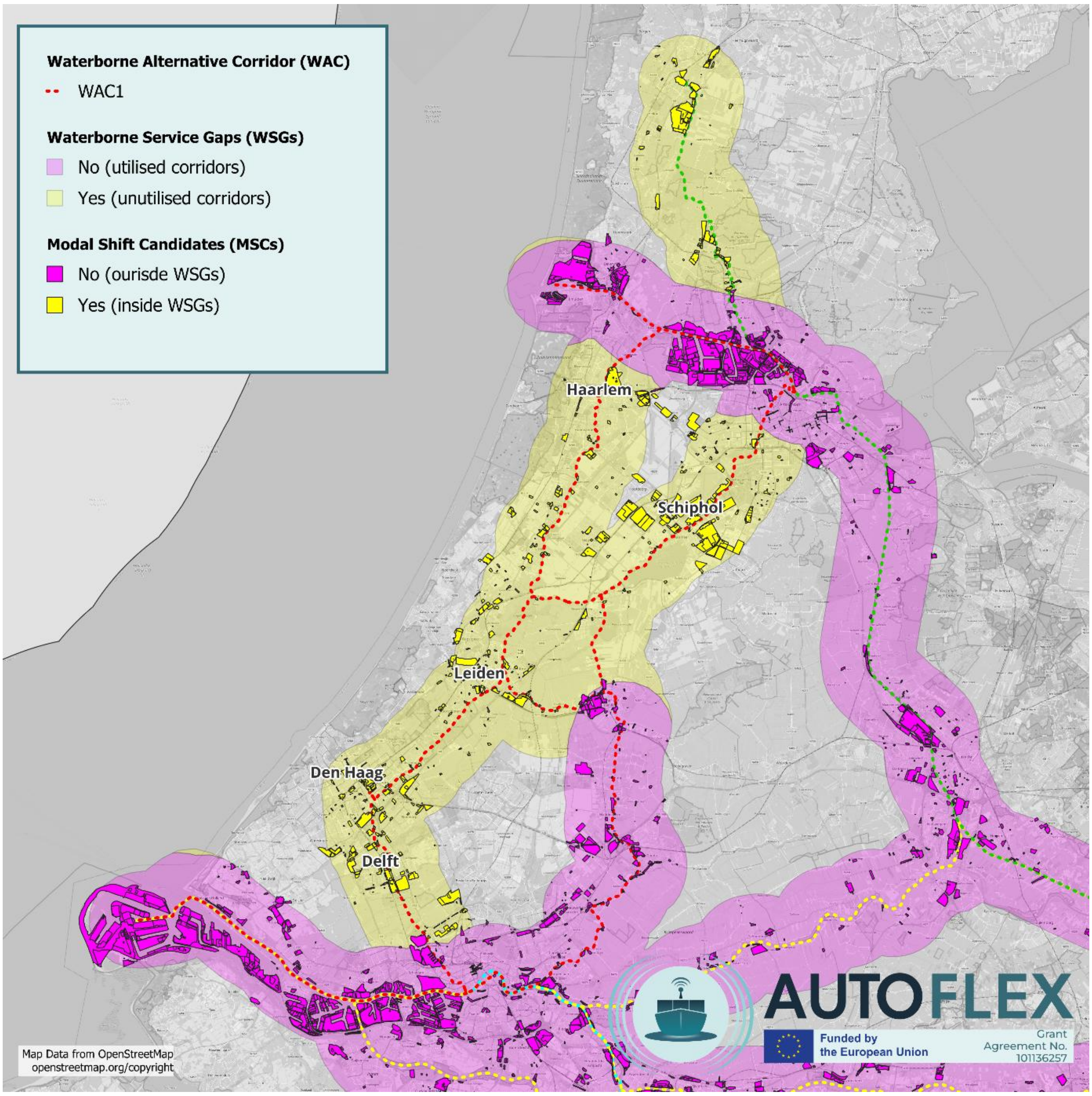

Figure 4-12: Clusters of Modal Shift Candidates (Targets) - MSCs in WAC1

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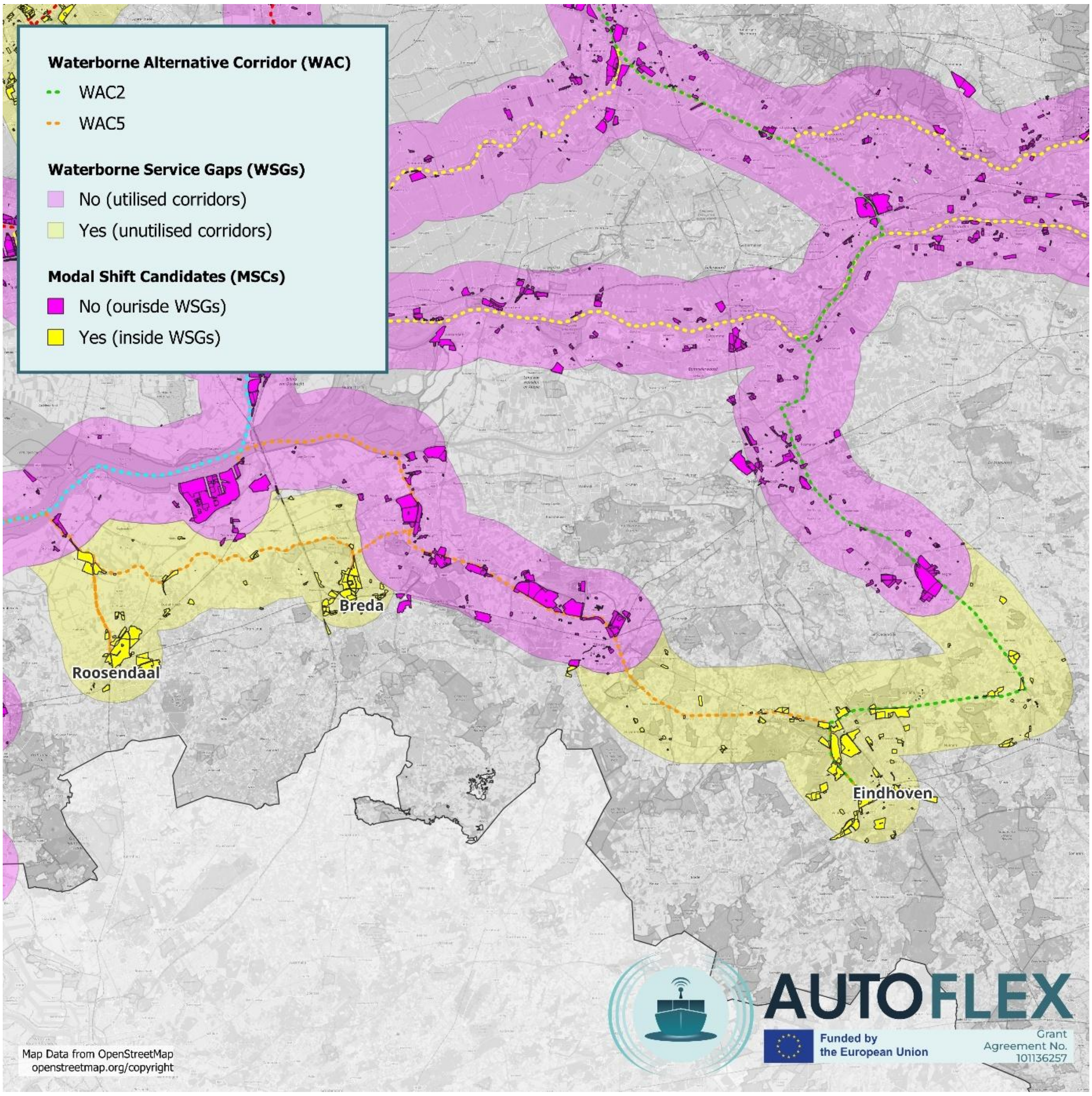

Figure 4-13: Clusters of Modal Shift Candidates (MSCs) in WAC5 (and southern end of WAC2)

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4.6 (F) RENEWABLE ENERGY SOURCES (RES)

While WAC1 and WAC5 (and to some extent WAC2) are important corridors for investigating potential modal shift use cases, especially from the perspective of TPTs and MDCs, it is equally important to establish that the AUTOFLEX IWT system itself must be considered as part of a larger, holistic waterway network that encompasses both utilised, underutilised and unutilised waterways through which an IWT transport ecosystem can be established. That is, while the AUTOFLEX transport services target clusters of modal shift candidates that currently do not have access to a waterborne transport alternative, the AUTOFLEX transport services must also seamlessly integrate into a broader European transport ecosystem to be effective. Thus, the investigation on potential locations for SCH hubs apply across all the WACs, seeing each of these as an integrated line in a larger inland waterway transport network (like metro lines in an urban mobility network). The challenge is to find locations for placing SCHs which together will ensure sufficient range for the AUTOFLEX vessels operating on the routes of the network, and which makes route connections for cargo transfer efficient. Furthermore, these SCH locations may be able to provide energy to other services beyond the AUTOFLEX transport system into the larger IWT ecosystem. Figure 4-14 shows an overview of energy sources in the Netherlands. Do note that although one type of energy source is widely distributed, this does not necessitate that this energy source is the highest contributor to the overall energy balance of the country (e. g., a single nuclear plant may produce the equivalent amount of energy as millions of solar panels). Consequently, Figure 4-14 cannot be used to establish the percentage of the visualised energy sources within the overall energy balance, but it can be used to establish the availability of energy sources locally.

As can be seen from Figure 4-15, each WAC has various potential renewable energy sources to tap into. Thus, each WAC is analysed in terms of geographic, navigational characteristics, terminal infrastructure, renewable-energy availability, and compatibility with ZESpack-based operations. In doing so, the full operational context for the AUTOFLEX vessel can be established by relating its performance, energy demand, and logistical characteristics to real corridors and terminals. Said differently, the location of Stow&Charge hubs (see section 6 STOW&CHARGE) will be intimately tied to the operational performance and range of the AUTOFLEX vessel as the alpha omega variable. Said differently, the operational performance of the AUTOFLEX vessel within the WACs determines where Stow&Charge hubs can be deployed, how many ZESpacks are required in circulation, and how terminal-side energy buffers should be dimensioned. This includes potential cross-sections between WACs so that the Stow&Charge Hub could service multiple WACs simultaneously without necessitating multiple transhipments. Subsequently, having accounted for this, the Stow&Charge locations would be chosen based on the location of existing renewable energy sources that could be tapped into.

Table 4-6: Energy availability and potential for Stow&Charge Hubs in the WACs

WAC1	The first route within *(Amsterdam – Schiphol – Alphen a/d Rijn – Gouda – Rotterdam)* constitutes 87 km of inland waterways and is the shortest route in the WAC. In general, it is one of the most suitable routes for fully battery electric operations. It includes the existing ZES charging station at Alphen aan Rijn, making this trajectory the most practical initial demonstration corridor that expands upon already existing renewable energy efforts within the AUTOFLEX use case area. Terminals along the route include Schiphol, Alphen and Gouda and offer strong multimodal connections and sufficient container

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	handling capabilities. The second route *(Amsterdam – Haarlem – Leiden – Den Haag – Rotterdam)* constitutes 92 km of inland waterways and runs through Amsterdam, Haarlem, Leiden, Den Haag and Rotterdam. This near coast route links major urban regions and includes multiple terminals embedded in renewable energy dense zones. Terminals along Haarlem, Leiden and Den Haag vary in container-handling capability but collectively offer strong potential for decentralised Stow&Charge integration. Across both of the WAC1 routes, terminal accessibility is high and sailing distances are well within the vessel's effective ZESpack range for sailing speeds of 7–8 km/h (see section 1.4.3). WAC1 therefore represents a feasible operational basis for an early Stow&Charge validation.
WAC2	The longest of all designated AUTOFLEX corridors, covering 241 km and connects the northern, central and southern logistics hubs of the Netherlands. It begins in Alkmaar, proceeds into Amsterdam, and continues through Utrecht toward the southern industrial region of Tiel, 's Hertogenbosch, Veghel, and finally Eindhoven. This corridor represents a full north–south traverse of the Dutch inland waterway network and could be an important corridor for the distribution of containerised energy throughout the AUTOFLEX transport ecosystem. Major logistics hubs such as Utrecht, 's Hertogenbosch and Eindhoven offer container-handling equipment and sufficient connections to rail and motorway systems along with, presumingly, substantial cargo volumes and transport demands. The overall length of 241 km implies that multiple locations with charging stations or ZESpack exchanges must be created, making this route highly challenging for energy buffering and optimal hub placement. In addition to its length, the route passes through regions with significant solar-fields and rooftop solar potential, offering opportunities for local renewable electricity generation for Stow&Charge hubs.
WAC3	Comprises a 134 km loop connecting Rotterdam with the eastern inland terminals of Gorinchem, Tiel, Nijmegen, and Arnhem, before returning along the same trajectory. This route crosses regions with strong renewable-energy facilities, particularly around Nijmegen and Arnhem, where widespread wind and solar installations can be found. Terminals along Gorinchem, Tiel and Nijmegen vary in handling capability but collectively provide adequate conditions for decentralised ZESpack operations. Because this route features a defined out and return structure, it is well suited for analysing cyclical ZESpack logistics, vessel scheduling models, and daily energy consumption patterns.
WAC4	Represents a major industrial corridor extending from Rotterdam into southern Netherlands and northern Belgium along its 127 km of inland waterways. The operational route includes Rotterdam, Dordrecht, Moerdijk, Bergen op Zoom, and, potentially, Antwerpen, covering a total distance of 127 km. All major terminals along this route feature strong multimodal connections and varying levels of container-handling capability. Moerdijk, with its extensive wind farms and solar fields, stands out as one of the most promising hubs for high-capacity Stow&Charge implementation. The corridor starts/ends in both Rotterdam and Antwerpen, the two largest seaports of Europe and may therefore offer unmatched quay-infrastructure facilities and substantial renewable-energy potential. WAC4 thus forms a natural high-demand axis where multiple vessels may operate simultaneously, justifying the installation of larger Stow&Charge facilities.
WAC5	Covers 211 km of inland waterways and connects key Dutch inland logistics centres south of Rotterdam. It starts at Moerdijk, proceeds through Breda and Tilburg, and continues onward to Eindhoven and Helmond (or vice versa). This corridor crosses regions with substantial industrial activity and high solar field

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	density, particularly around Breda and Tilburg. Terminals along this route generally possess container-handling equipment or sufficient quay capabilities to support ZESpack exchange operations. With its combination of distance and terminal infrastructure, WAC5 resembles an excellent testbed for medium range battery electric operations and energy buffer planning.

The following figure shows possible stow & charge location as well as existing wind turbines and wind parks in the area of interest for the AUTOFLEX transport system.

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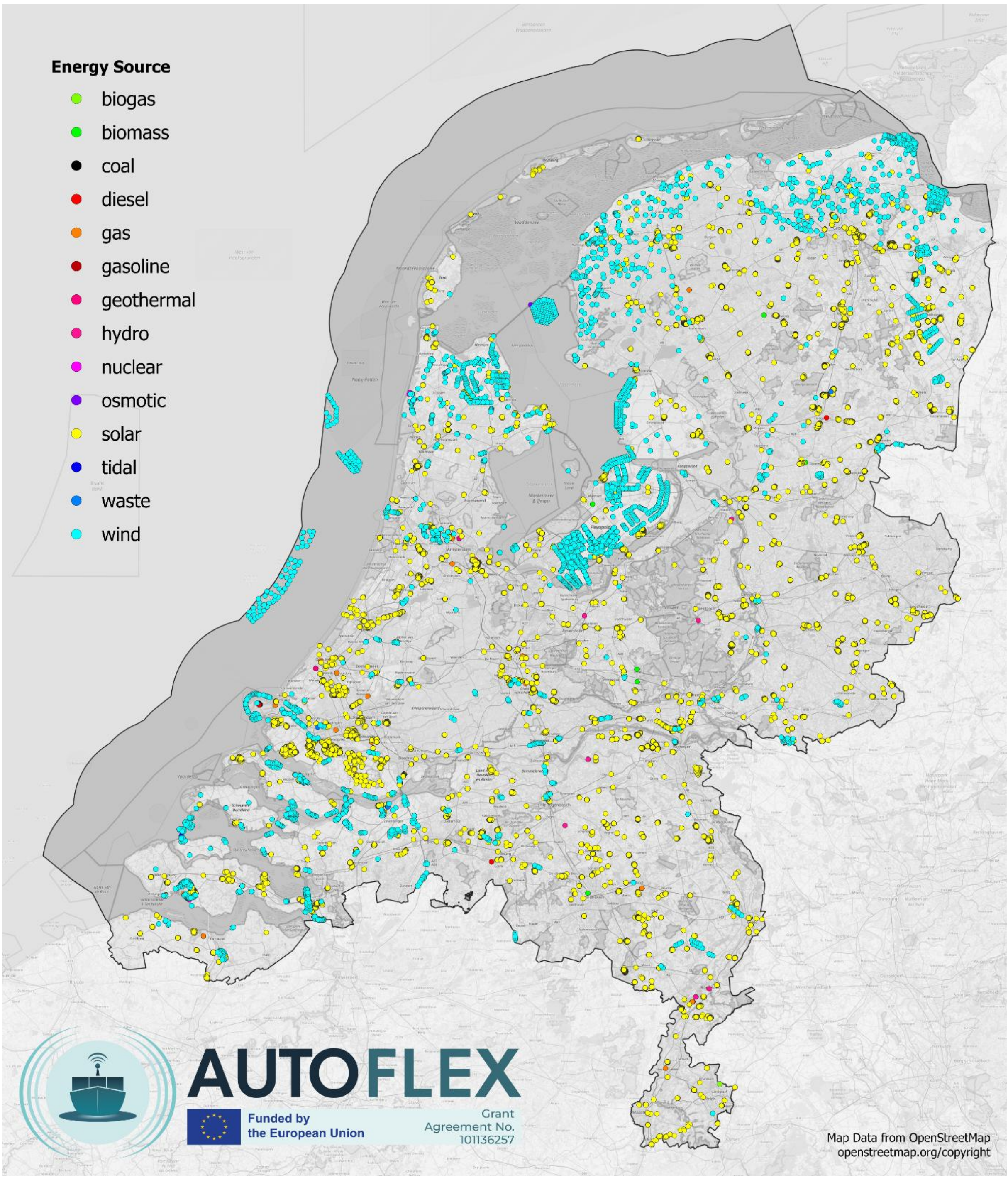

Figure 4-14: Potential energy sources

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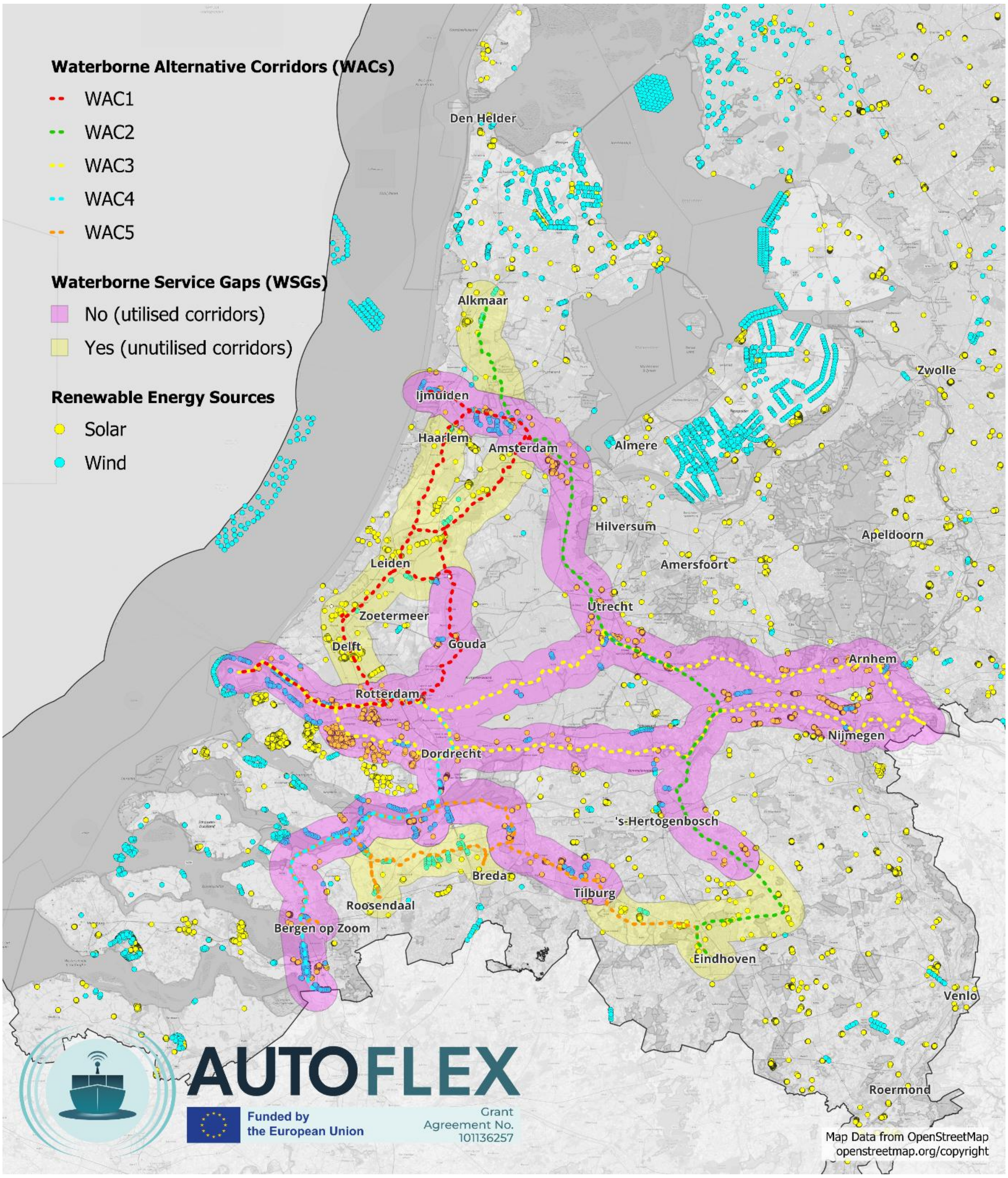

Figure 4-15 Renewable Energy Sources (Solar & Wind) and the Waterborne Service Gaps (WSGs)

5 TEMPORARY PORT TERMINALS

5.1 INTRODUCTION

The discussion in chapter 3 identified economies of scale, cargo centralisation and the marginalisation of small ports as the main challenges to be solved for realising a modal shift from roads to waterways. The proposed solution was to reintegrate SMPs through innovative terminal concepts that offer scalable and adaptable solutions that can revitalise SMPs, especially along unutilised and underutilised inland corridors. In this chapter, the clusters of Modal Shift Targets (MSTs) from Chapter 5 are investigated to identify locations where the AUTOFLEX transport system may feasibly enable modal shift from road to water. Following this investigation, the common transshipment denominators across the locations are identified and used as the design requirements for the Temporary Port Terminal (TPT) concept. Subsequently, the preconditions and building blocks of the TPT are listed, followed, by a few examples of TPT constellations based on a few archetypical contexts found in the investigation of MSC clusters. As such, this chapter documents the results of the AUTOFLEX task 3.1 (see section 1.3.2).

The idea of a temporary terminal concept is not unique to the AUTOFLEX project, and as observed in our analysis herein, some semi-temporary applications in bulk and breakbulk cargo have already been deployed in our use case area. These applications provide valuable information for the development of the TPT concept.

5.2 METHODOLOGY

While the definition of task 3.1 (see section 1.3.2) includes a short method description, this section outlines a more elaborated definition of the methodology that was applied to derive requirements and inspiration for designing the TPT concept. This chapter will comment on this methodology more in detail.

5.2.1. RESEARCH APPROACH

The following approach was taking to the analysis:

1. The investigation departed from the results of AUTOFLEX WP2 task 2.1 [10], which mapped roads with high transport related traffic, waterways, infrastructure, etc.
2. First the geographical scope was narrowed down to the clusters of Modal Shift Candidates (MSCs) within WACs 1 and 5, see the analysis in chapter 4 . These are areas close to, or containing, potential transport customers that have no existing inland waterway container transport services today.
3. Then, these MSCs were screened through photography analysis of satellite images from Google Earth to identify candidate locations that could benefit from a waterborne transport service, and which it would be possible to call to with the AUTOFLEX vessel.
4. Candidate locations were investigated in more detail, through historical Google Earth images, Google Street view images from Google Maps, and information on businesses and organisations located at or near the locations, available online (predominantly through Google-derived maps and images).

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5. To derive requirements and design inputs for the TPT concept, the location investigation addressed the main question "What would it take to do container transfer at this location?" through investigating and discussing:
    a. How could cargo handling be solved?
    b. Is there sufficient space (for the AUTOFLEX vessel to call to the location, for quay side cargo handling equipment such as reach stackers, for storage of containers, etc.)?
    c. What is the state of the waterfront (growth, need for upgrades, or indications of being in use, etc.)?
    d. What critical infrastructure is already there, or what infrastructure is missing (bollards for mooring, cranes, fencing, the quay, roads, etc.)?
    e. What are the local businesses or the public at or near the location (conflict of interest, potential interest for the transport service, etc.)
    f. What investments would have to be made (e. g., development of brownfield areas for storage or quay extension, or upgrading infrastructure)?
    g. Are there any objects, structures, etc., that would have to be moved, modified or demolished?
6. Then, finally, the observations and findings were discussed and synthesised into general requirements and design considerations, leading to the proposed TPT concept where different possible solutions for realising the required functions are proposed.

While the task description in section 1.3.2 mentions that ISPS regulations will be considered, the final AUTOFLEX vessel design implies that it is not subject to these regulations. This is because the AUTOFLEX vessel is around 250 GT and vessels below 500GT are exempted [13]. Furthermore, most of the operations of the AUTOFLEX vessels will likely be between inland terminals and TPTs (or directly between TPTs) in domestic trade (i.e. between one of the larger Dutch seaports and the smaller inland terminals), making the ISPS regulations entirely irrelevant. Nevertheless, safety and security are still important concerns which implies that TPTs might have to include some mechanisms for controlling access to the ship and terminal area. Both for the safety of people, and for security of cargo and equipment against, e. g., theft or vandalism.

In the following analysis, two identified examples of TPTs in real operations are observed: one for bulk and break bulk respectively. These will be discussed more in sections 5.3.3 and 5.3.4. However, at present, it is worth noting that these two examples indicate that the required control of access through physical barriers is not as strict as initially anticipated when comparing to ISPS requirements. However, the identified examples involve both/either conventionally crewed barges and/or non-propelled barges. For an uncrewed autonomous ship, as per the AUTOFLEX transport system, some measure for preventing unauthorized access to the ship is assumed to be required in some shape or form. While it could be assumed that the AUTOFLEX vessel calls to TPTs only when there are human operators at the TPT for handling cargo, and that these operators could also handle safety and security concerns, such safety and security constellations would not cover periods where no operators or vessels are present. This might be fine for a bulk or break bulk TPT, as the value of the cargo and its physical properties implies low risk of theft and vandalism. However, containerised cargo could potentially (and will most likely) contain higher value commodities. Furthermore, safety during heavy lifts such as when handling containers is easier to manage if access is restricted. Finally, unauthorised access to uncrewed ships would also be easier to manage if access points are limited. Consequently, while the ISPS regulations were deemed to be entirely

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irrelevant for the TPT concept in the context of the AUTOFLEX transport system, inferences on how to maintain the security (and safety) remains an important aspect of the TPT concept.

5.2.2. THE AUTOFLEX VESSEL

As the TPT will be designed to facilitate the construction of the AUTOFLEX transport system, it needs to be aligned with the AUTOFLEX vessel design. Specifically, the vessel main dimensions will be considered in the evaluation of quay space, and accessibility. Vessel height will be used to evaluate if fixed bridges can be passed, as some promising locations are not reachable due to such hindrances. Section 1.4 gives an introduction to the AUTOFLEX vessel, including the main dimensions needed for the TPT analysis.

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5.3 POTENTIAL TRANSHIPMENT LOCATIONS WITHIN THE MODAL SHIFT CANDIDATE CLUSTERS

This chapter explores the possibility of undertaking transhipment operations within the identified clusters of Modal Shift Candidates (MSCs) vis-à-vis section 4.6 . The purpose is to identify the potential opportunities and challenges, including necessary adaptations and limitations, with regards to establishing a transhipment concept at the site in question. Through this, the analysis aims to build a comprehensive, empirically-driven understanding of the design requirements of the TPT concept, including both theoretical and practical parameters of the development and deployment of the TPT. While the purpose of the section is not to analyse and conclude on the concrete TPT locations for the AUTOFLEX transport system, it will also serve as input for the upcoming transport system design.

5.3.1. MSC CLUSTER 1: HAARLEM

Haarlem is located west/southwest of Amsterdam and consists of both residential and industrial areas. For the purposes of the Modal Shift Opportunity Area (MSOA), a larger industrial area can be found with a waterborne interface along the *Noorder Buiten-Spaarne* canal (1 in Figure 5-2) and an appendix to that canal called *Industriehaven te Haarlem* – literally, the industrial port of Haarlem (2 in Figure 5-2).

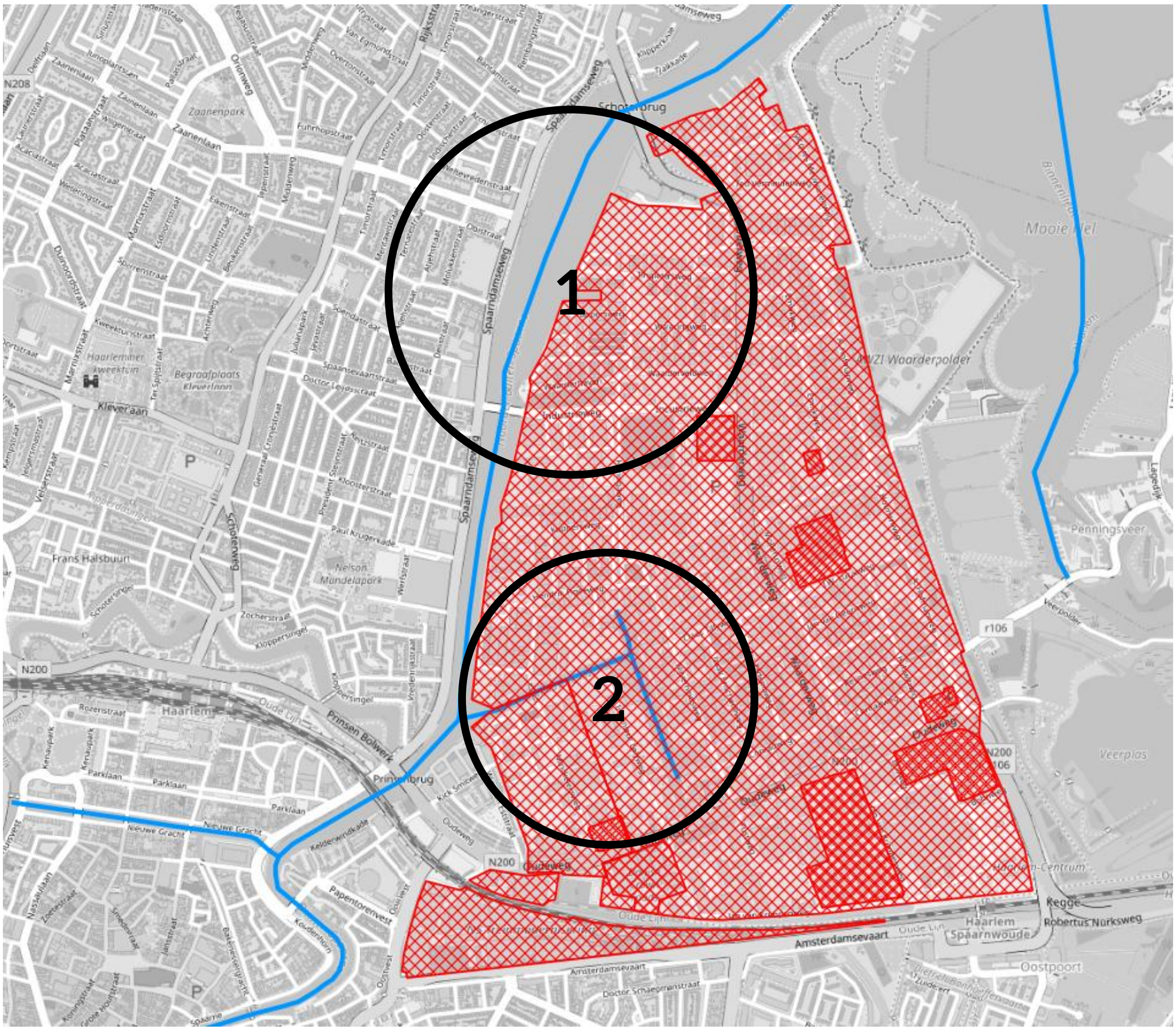

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Figure 5-2 Industrial area(s) of Haarlem, Maps data: © OpenStreetMap| © EuRIS

5.3.1.1. HARLEEM AREA 1: NOORDER BUITEN-SPAARNE CANAL

Moving to the second waterborne interface area along the *Noorder Buiten-Spaarne* canal (see Figure 5-3), one again finds three potential areas for deploying a TPT concept: a large brownfield under development in the north (red #1 in Figure 5-3); another brownfield adjacent to what appears to be a container depot (red #2 in Figure 5-3); and the site of a sewing machine manufacturer (red #3 in Figure 5-3).

Figure 5-3 Noorder Buiten-Spaarne Canal Maps Data: © Google | © 2025 Airbus

First, the northern most potential TPT application is a brownfield seemingly under development (a former *Prins Staal* steel wholesaler and distributor). The location is marked in red #1 in Figure 5-3 and can be found in detail in Figure 5-4. The area is significant in size and has a lot of surrounding businesses and access points, which could make it a significant TPT in volumes. On the waterfront, a clear quay area is available with multiple barges and pontoons (i.e. not self-propelled barges) moored in the near vicinity of the quay (when flicking through historical satellite imagery of the location, one will also find these barges and pontoons moored alongside the quay itself). This, again, displays a potential need for TPTs to offer waterborne storage options via floating storage units, but also indicate that the quay itself is capable of providing mooring to [illegible]

Figure 5-1 Industrial site of Haarlem

[illegible] meters, giving it the option of hosting multiple AUTOFLEX vessels simultaneously, with the overall area being around 35.000-40.000 m^2, thus providing more than sufficient space for transshipment and storage purposes. Furthermore, the group of barges laying off the terminal "behind" a line of wooden pillars sticking out of the water could offer anchoring options for inland vessels and be an opportunity to drop-off pontoons/barges without necessarily mooring them to the TPT quay itself – for instance, if the TPT is not "open"/"active" in the hours when the barge arrives at the location. Thus, this may allow for asynchronous transhipment and transport activities, as pontoons could be loaded and positioned in this "waiting area" for a push barge to arrive. Comparing historical satellite imagery, it appears that the current activities in the area are related to *tearing down* the previous building –

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potentially with the intention to erect a new building or to leave the area a brownfield. Local visits will be needed over a prolonged period to establish the plans for this area more precisely in order to subsequently evaluate its relevance vis-à-vis the TPT development. In sum, depending on what the future of the brownfield may hold, this location could be relevant for deploying a TPT concept.

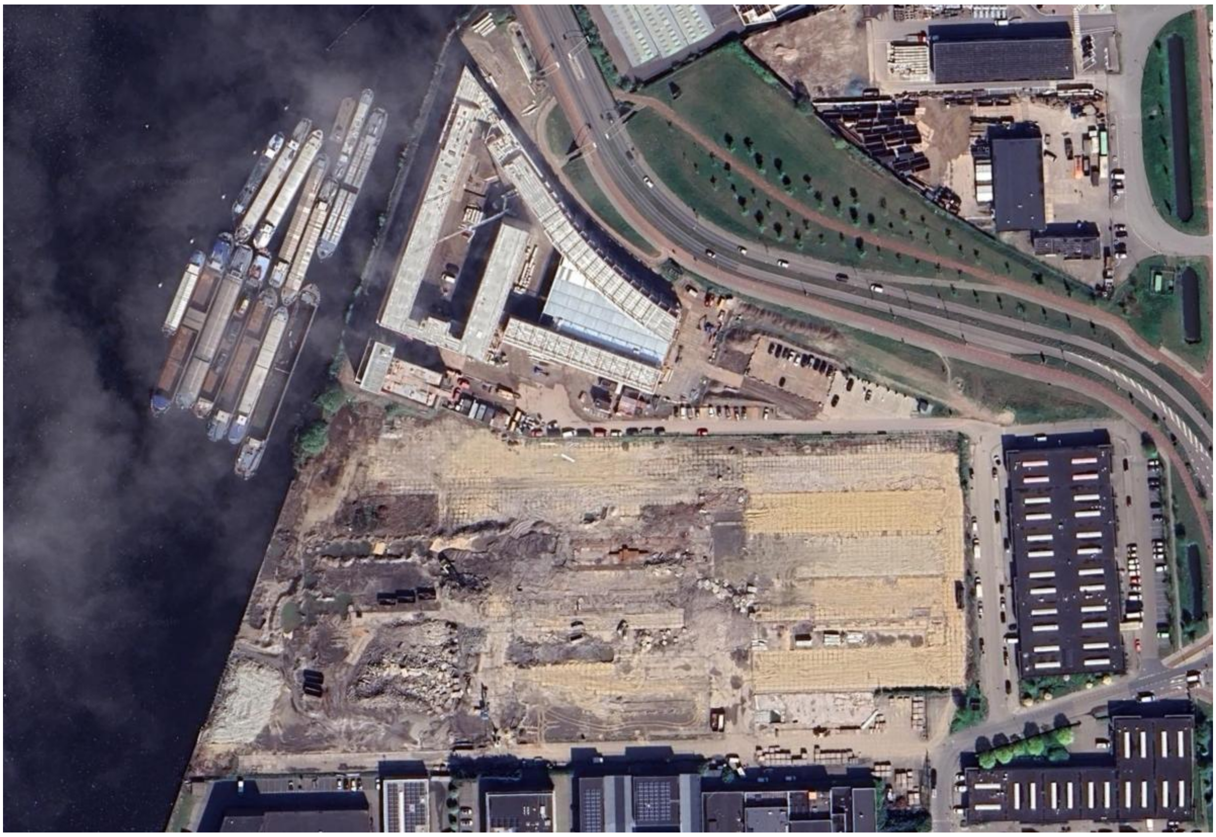

Figure 5-4: Brownfield area northern part of Noorder Buiten-Spaarne canal
Maps data: © Google | © 2025 Airbus

Second, another potential TPT location is another, smaller brownfield just south of the larger sandy brownfield. This site is marked as red#2 in Figure 5-3 and can be found in detail in Figure 5-5 (left). The location offers both a steady quayside, limited overgrowth and a smaller storage area. Being surrounded by businesses, there could also be storage offered somewhat off-site from the TPT, particularly two larger estates located right behind the location which are currently used for storage in containerised compartments. This location has the same opportunities and challenges as the other brownfields mentioned in this section and will be considered for TPT application. The quay is ca. 60 m. in length, with the overall area constituting ca. 3.000 m^2, which should provide ample space for both transhipment-related and storage-related activities. Furthermore, in the near vicinity of the brownfield, what appears to be a container storage depot of around 10.000 m^2 of the name *Box Huur Haarlem*: a company offering self-storage units. This could potentially work well either as a potential storage buffer, should the brownfield experience exacerbated volumes, or as a form of creating a storage setup which is asynchronous with the transhipment site. Said differently, if the TPT activities can be aligned with the storage depot, then transport units could potentially be placed within one of the self-storage units both for incoming and then picked up for last mile without relying on the timely synchronisation with the operations of the TPT. Similarly, for outbound cargo, the cargo unit could be placed safely and securely within the self-storage unit and then transferred to the TPT handling area in due time for it to be

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transhipped to the inland vessel. This time-based asynchronization means that the TPT concept can function more independently from the hinterland transport, which may make its operationally and financially more plausible. Road access is likewise rather convenient, with road connections both to the north and to the south of the premise. Furthermore, the premise is fenced off which means that a higher ISPS level could potentially be deployed here.

Figure 5-5: Left: Brown field area middle Noorder Buiten-Spaarne canal | Right: Sewing macine factory Noorder Buiten-Spaarne canal.
Maps Data: © Google | © 2025 Airbus

Third, a sewing manufacturer can be found near the water. This has been marked as red #3 in Figure 5-3 and can be found in detail in Figure 5-5 (right). While the authors have had difficulties establishing if this location is an actual sewing machine production facility, a larger distribution centre or a location actively engage with the act of *sewing* itself, it is safe to say that the area could potentially be used for a TPT concept. Today, there is more than 90 meters of available quay infrastructure, with an additional 50 meters of quay development potential available on each side of this. Furthermore, the operational area near the quay is a little more than 12 meters wide, making it a total of minimum 1.000 m^2 available for transhipment purposes and immediate storage. Furthermore, to the north of the main building on the premises, a larger undeveloped area exists which could potentially be repurposed into a storage area if there is need. However, when inspecting historical satellite imagery going back to the 1980s, it appears that the area never has been developed, which means that it may not have a "hard" ground surface as seen in other brownfields within this analysis (that is, brownfields that have previously been used as important infrastructure, but which have been abandoned and taken over by vegeation). To the south of the main building is a dog care, *Hotdoghouse Haarlem*, with a larger open field (presumingly for the dogs to run around outdoors). This area could potentially be partly integrated into the TPT concept at the premises outside of the opening hours of the dog care – that is, from 1800-0800 on weekdays and all of Saturday and Sunday. Given the potential scope of transports within the context of AUTOFLEX, it is not unlikely to think that the site would be visited only on the weekends

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when both the dog kennel and the sewing machine companies appear to be otherwise closed. Depending on how the main building is laid out internally, cargo handling equipment such as reach stackers and terminal tractors could potentially be stored away within these building whenever transshipment activities are not ongoing – for example in one of the northern-most buildings (as seen on Figure 5-5, right)

5.3.1.2. HAARLEM AREA 2: INDUSTRIEHAVEN TE HAARLEM

Beginning with the latter, *Industriehaven te Haarlem*, one finds several potential TPT locations, see Figure 5-6. Several industrial PoIs are present around the waterfront. First, a multitude of businesses of various sorts are present, including wholesalers, retailers and smaller manufacturers. While none of these sites offer an immediate interface for a potential TPT location, they do testament to the potential interest in transport services that could come out of the basin. In addition, while a nice pier exists at the very end of the basin, it is currently occupied rather permanently by a floating hotel/restaurant establishment, making it a potential TPT location should the hotel/restaurant decide to terminate its operation there but not before such termination. Of the existing transhipment activities, three highlights should be mentioned: a cement manufacturer and two separate waste and recycling centres.

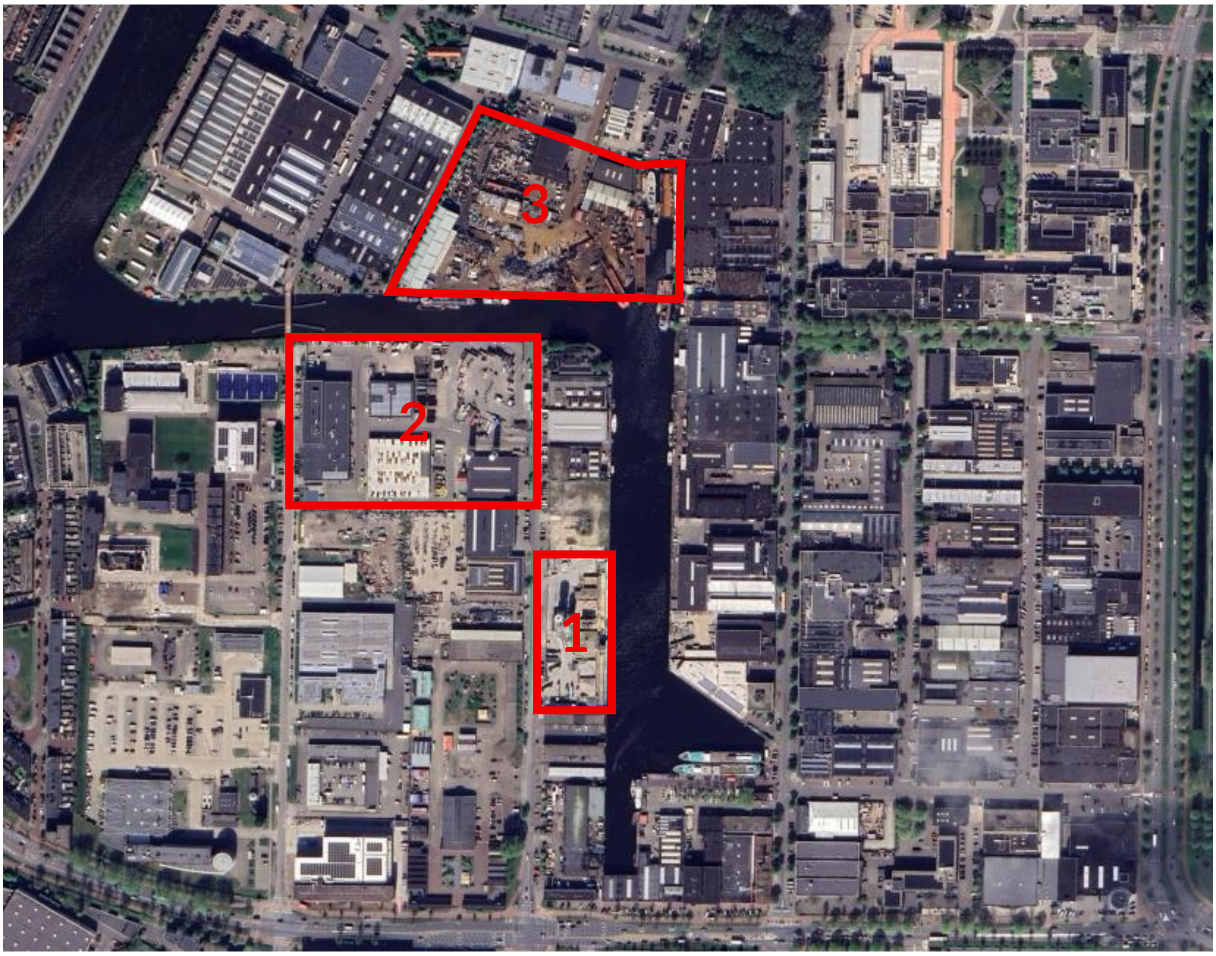

Figure 5-6: Industriehaven te Haarlem
Maps data: © Google | © 2025 Airbus

First, a cement manufacturer is located right next to the water (red #1 on Figure 5-6), which loads and unloads dry bulk cargoes unto inland vessels of similar type. However, when investigating more closely (see Figure 5-7), one finds that there is limited surface area that

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could be used as storage area within the premises. However, should the cargo be destined directly to one of the adjacent businesses, it could potentially be that the storage area of the terminal is "remote" in the sense of not immediately next to the quay. While this could potentially solve storage area issues for TPTs, it may add additional operational complexities and potentially slow down transhipment times if the cargo handling equipment cannot immediately unload the cargo unit quayside but instead have to drive it a noticeable distance before dropping it off. Oppositely, it may allow TPT constellations to waterborne interfaces with limited quayside storage area, but with a noticeable adjacent storage area. Furthermore, in many areas, waterfront real estates are often more valuable than real estate a little more removed from the waterfront, potentially allowing attracting urban development (whether residential or commercial, although the latter may be more relevant from a noise-pollution perspective), while still allowing for IWT services to the location. In addition to the manufacturer mentioned, a noticeable brownfield exists just beside the terminal (to the left in Figure 5-7), which could either work as a storage facility – or potentially as a TPT application in its own right. From satellite imagery, it seems that the infrastructure is still in good shape and could be somewhat easily converted to a TPT (i.e. it does not have a lot of overgrowth etc.). The overall area seems well fenced off, which would ensure the safety and security of the potential TPT operations at the site. While the waterfront is inhabited by a bulk crane of sorts that services the transhipment of, presumingly, cement, there is not a lot of access to this waterfront in general, nor is it fair to assume that the crane could reach beyond the cement compartments with loaded containers. Thus, if this site is to be used as a TPT deployment, it is recommended that the adjacent brownfield (left in Figure 5-7) is used as this provide both a quay of around 60 meters and an overall operational area of around 3.000 m2, which should be more than enough space to accommodate both transshipment and storage.

Figure 5-7 Cement manufacturer in Industriehaven te Haarlem
Maps data: © Google | © 2022 Vexcel Imaging US, Inc.

Second, a waste and recycling center (red #2 on Figure 5-6) is present with a seemingly opportune waterborne interface with a long quay space (around 175 meters in length) that could be used for mooring vessels. In the eastern side of the quay area (right in Figure 5-8) is a group of garbage containers, which could potentially be arranged differently to allow for more quay space for both transhipment and cargo storage. This area could, hypothetically, provide an overall area of around 4.000 m2, with a quay of around 60 meters in length –

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almost perfectly tailored to the AUTOFLEX vessels and with ample space for container storage. This is however entirely contingent on the option of removing the existing waste containers, which may not be possible without significantly compromising the operations of the site. In the western side of the quay area is a parking space (left in Figure 5-8), which, similarly, also potentially could be rearranged to allow for more available quay space. This area seems opportune for a potential TPT application as it provides a quay of around 100 meters in length and an operational area of around 2.500 m2 (depending on how the space is measured). Access-wise, there is fencing around the entire perimeter of the site, with a gate overseeing vehicles entrances and exits. Consequently, this area could potentially comply with harder access requirements that may be posed by customers, cargo types and/or regulations with regards to both safety and security. In addition, if the general modus operandi of the site allows, AUTOFLEX CEMT II vessel could potentially also support the recycling center with transport of recycled materials and/or waste to/from the premises.

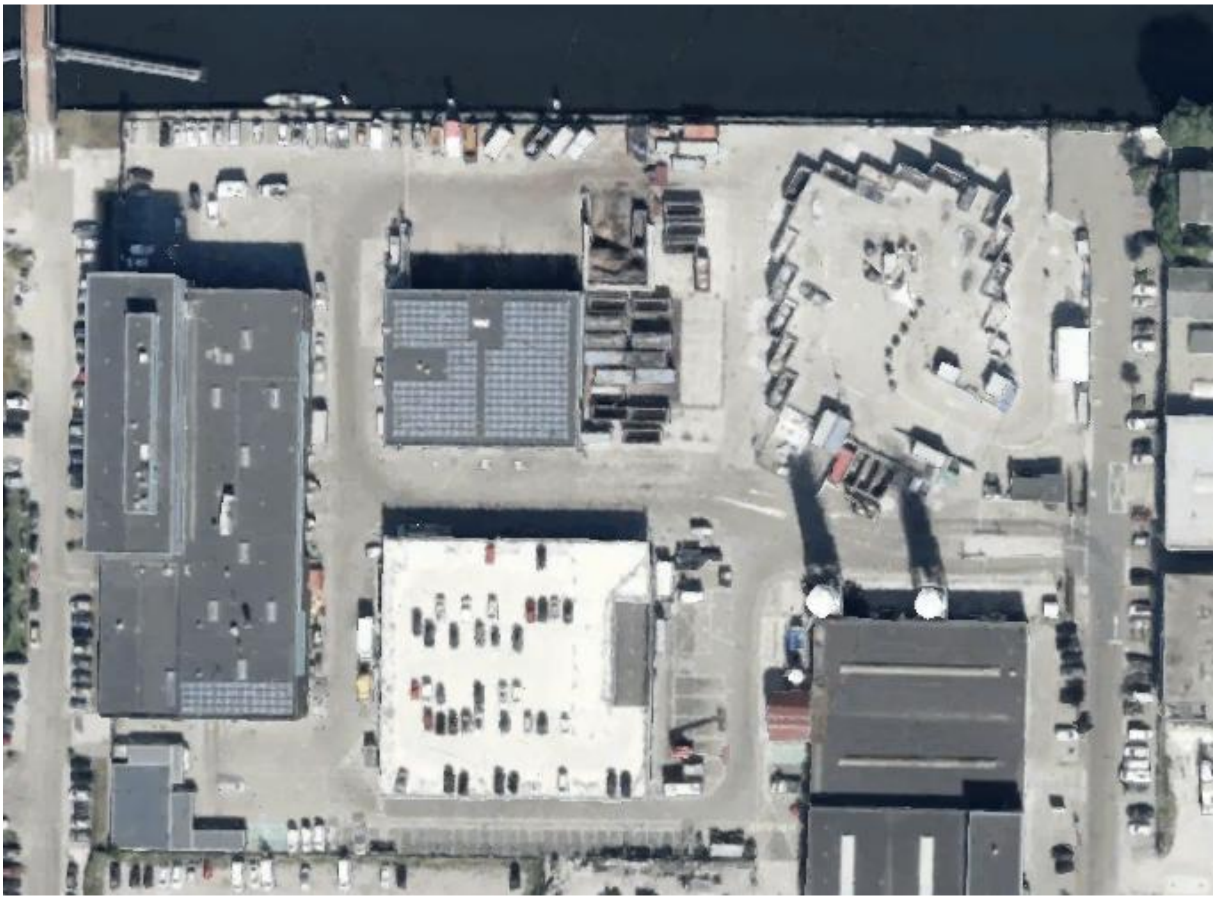

Figure 5-8: Waste and recycling centre in *Industriehaven te Haarlem*
Maps data: © Google | © 2022 Vexcel Imaging US, Inc.

Third, another waste and recycling center (red #3 on Figure 5-6), primarily used as a scrapyard and for metal recycling, is located with multiple inland vessels moored alongside its waterfront. In the eastern part, it seems that several vessels are grouped – supposedly stored temporarily until they themselves will be scrapped (see Figure 5-9). In the southern part, seemingly active transhipment activities are ongoing with inland vessels being loaded and unloaded with scrap metal. From the satellite imagery, it seems that inland vessels may potentially also be moored in a fully loaded state with no immediate intent to depart. This could potentially indicate that the terminal uses the barge as an extended storage option on

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the water outside of the premises on land. For a TPT concept, this could be an opportune solution to offer storage for locations with limited to no available storage area on the quay itself or within its near vicinity.

Figure 5-9: Waste management area in *Industriehaven te Haarlem*
Maps data: © Google | © 2022 Vexcel Imaging US, Inc.

5.3.2. MSC CLUSTER 2: SCHIPHOL

Schiphol is located south/southwest of Amsterdam and is home to one of the largest airports in Europe for both passengers and freight. Outside the airport, a few industrial locations can be found, with various small waterborne indents located along the eastern part of *Ringvaart van de Haarlemmermeerpolder*, see Figure 5-10. These various locations are predominantly warehouses and distribution centres associated with the airborne freight transport volumes in the airport. In addition, the airport itself has a multitude of businesses, ranging from stores to restaurants as well as various logistics- and maintenance-focused services (such as airplane repairs etc.). For the purposes of the MSOA, however, a lot of challenges were found vis-à-vis the conceptual development and practical deployment of a TPT concept. This was due to the following reasons:

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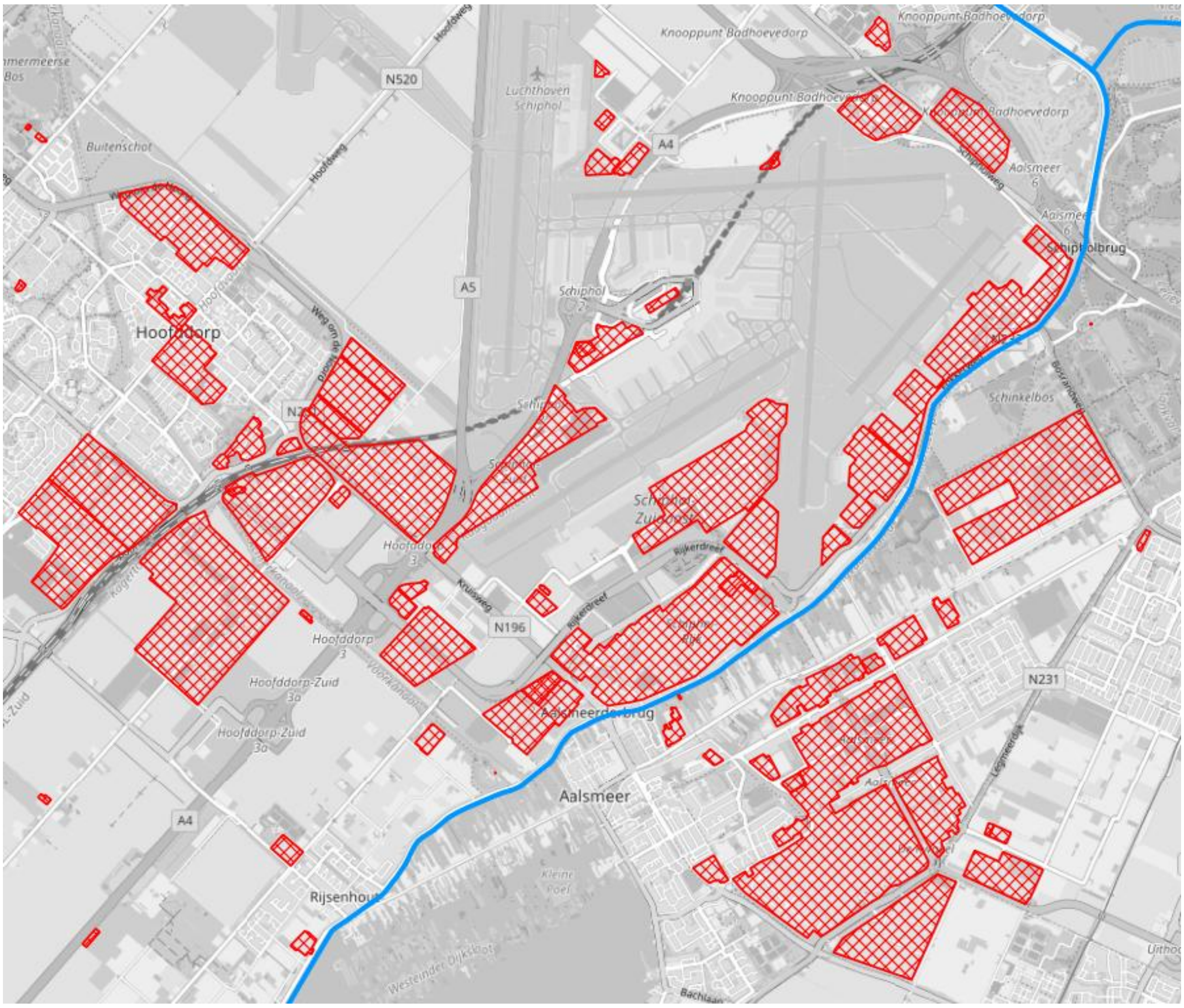

Figure 5-10 Industrial area(s) around Schiphol Airport
Maps data: © OpenStreetMap| © EuRIS

First, the predominance of residential housing alongside the far majority of the *Ringvaart* waterfront introduces a structural land-use challenge, if not incompatibility, with a TPT concept. Residential environments typically impose strict constraints on noise, vibration, operating hours, and visual intrusion – all of which are difficult to reconcile with regular freight transshipment activities through the TPT concept. Even relatively small-scale waterborne freight operations require manoeuvring space, quayside handling areas, temporary storage, and frequent vehicle movements, which collectively challenge residential amenity standards. In addition, limited waterfront availability restricts the possibility of developing dedicated logistics infrastructure or scaling operations over time. This can be seen exemplified in Figure 5-11. The presence of housing also constrains last-mile truck access, as residential streets are generally not designed for high volumes of heavy goods vehicles, creating both safety concerns and potential opposition from local residents. Furthermore, it may create significant safety and security hazards for all parties in the area, including potential damages to persons, equipment and/or cargo. Together, these factors significantly reduce the feasibility and long-term acceptability of a TPT operation in such a context.

Second, the existence of a public road running parallel to the canal for most of its length creates another challenge to TPT deployments. Any waterside transshipment activity would inevitably intersect with public traffic flows in some shape or form, which creates complex

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operational interfaces between freight handling and everyday mobility and increase the risk of congestion, accidents, and general traffic-related conflicts between road users. From a safety and security perspective, mixing public traffic with logistics operations raises additional concerns related to controlling access, managing incident, and complying with potential regulatory requirements which would need to be addressed in some shape or form. This is difficult as it is in industrial sites with mainly commercial road vehicles , and even more so in residential areas with potential soft road users such as bikes and pedestrians. While the authors do not argue that this poses an outright impossibility to the TPT concept, as we will also see later on in the analysis, it does require utmost care and coordination.

Figure 5-11 Example of a waterfront in the Schiphol industrial area
Maps data: © Google | © 2025 Airbus

Third, although speculative, it is fair to assume that while the area around Schiphol hosts a large concentration of logistics and distribution activities, the dominant cargo flows are tightly coupled to air freight operations that prioritise speedy deliveries. These characteristics may be less optimally aligned with an IWT concept, which typically offers advantages in cost efficiency and sustainability rather than transit time per se. As a result, the share of freight that is both physically suitable for transshipment through TPTs and operationally flexible enough to tolerate longer or less predictable lead times of IWT is likely to be small. This limits the potential for meaningful modal shift in the area and weakens the overall business case for establishing a TPT in the Schiphol area.

5.3.3. MSC CLUSTER 3: LEIDEN

Leiden is located almost directly between Haarlem and Rotterdam and is host to more sporadically distributed industrial areas that could be targeted for modal shift. These areas starts from the northeastern part of the area, on the *Rijn* canal running through the city toward the center of the city and expanding both northwards towards Haarlem on the *Zijl* and eastwards towards Alphen an den Rijn on the *Oude Rijn* (which is also the name of the waterway running through the city itself and out into the North Sea northwest of the city).

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A total of five Modal Shift Opportunity Areas (MSOAs) were identified in and around Leiden. These are indicated with numbers on Figure 5-12.

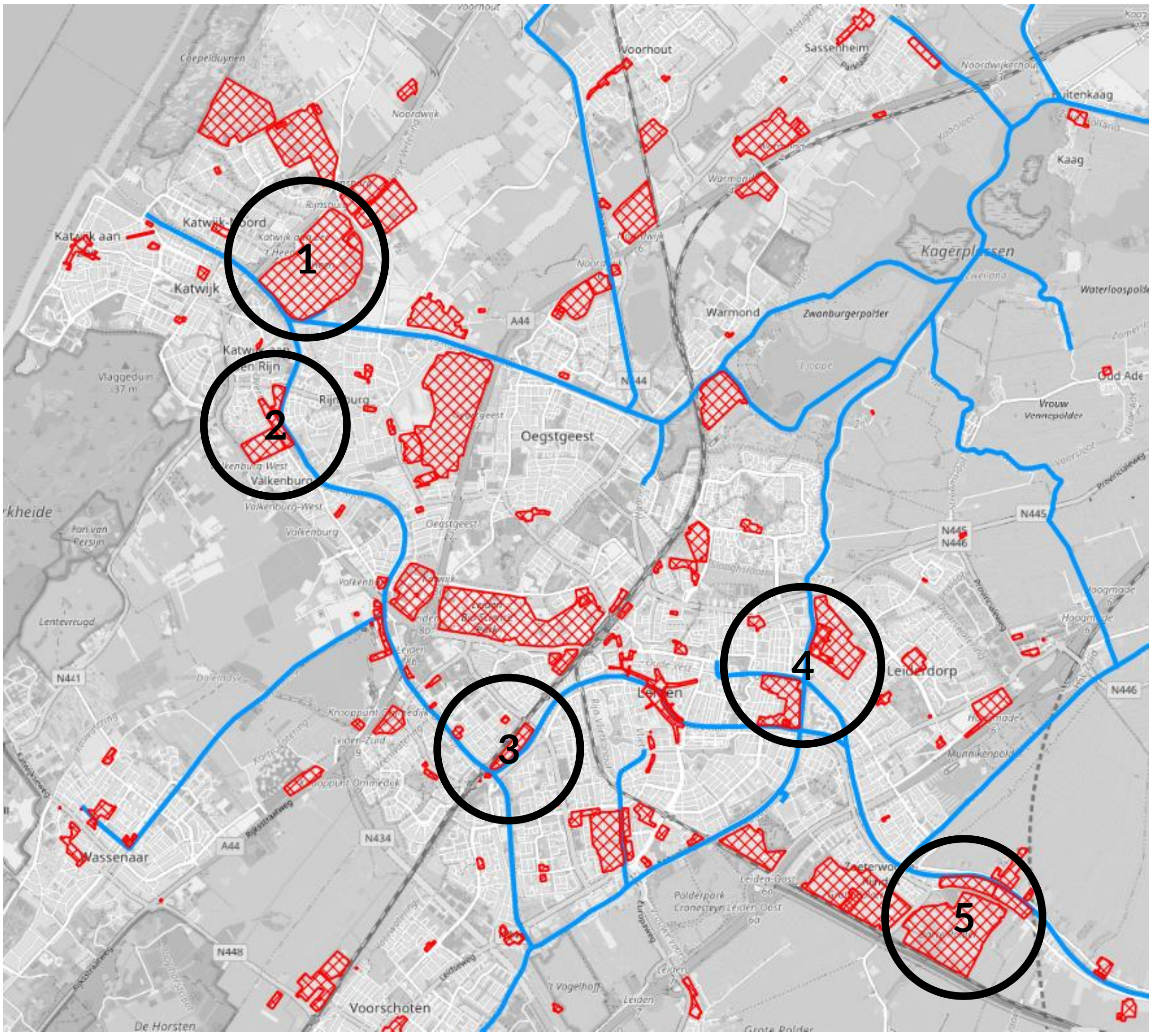

Figure 5-12 Industrial area(s) of Leiden
Maps data: © OpenStreetMap| © EuRIS

5.3.3.1. LEIDEN AREA 1: *HEEN INDUSTRIAL PARK*

On the northwestern part of the Leiden area (area 1 on Figure 5-12*)* along the canal with two waterborne interfaces: one on the *Oude Rijn* itself and one of a small appendix to said canal, called the *Maandagse Wetering* (see figure Figure 5-13 – waterway in the top is the *Oude Rijn*, while the waterways to the left is the *Maandagse Wetering*). The area is officially part of the

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town *Katwijk aan Zee*, but will be considered as part of the greater MA of Leiden for the purposes of this report. The points of interest in this area can be defined as follow.

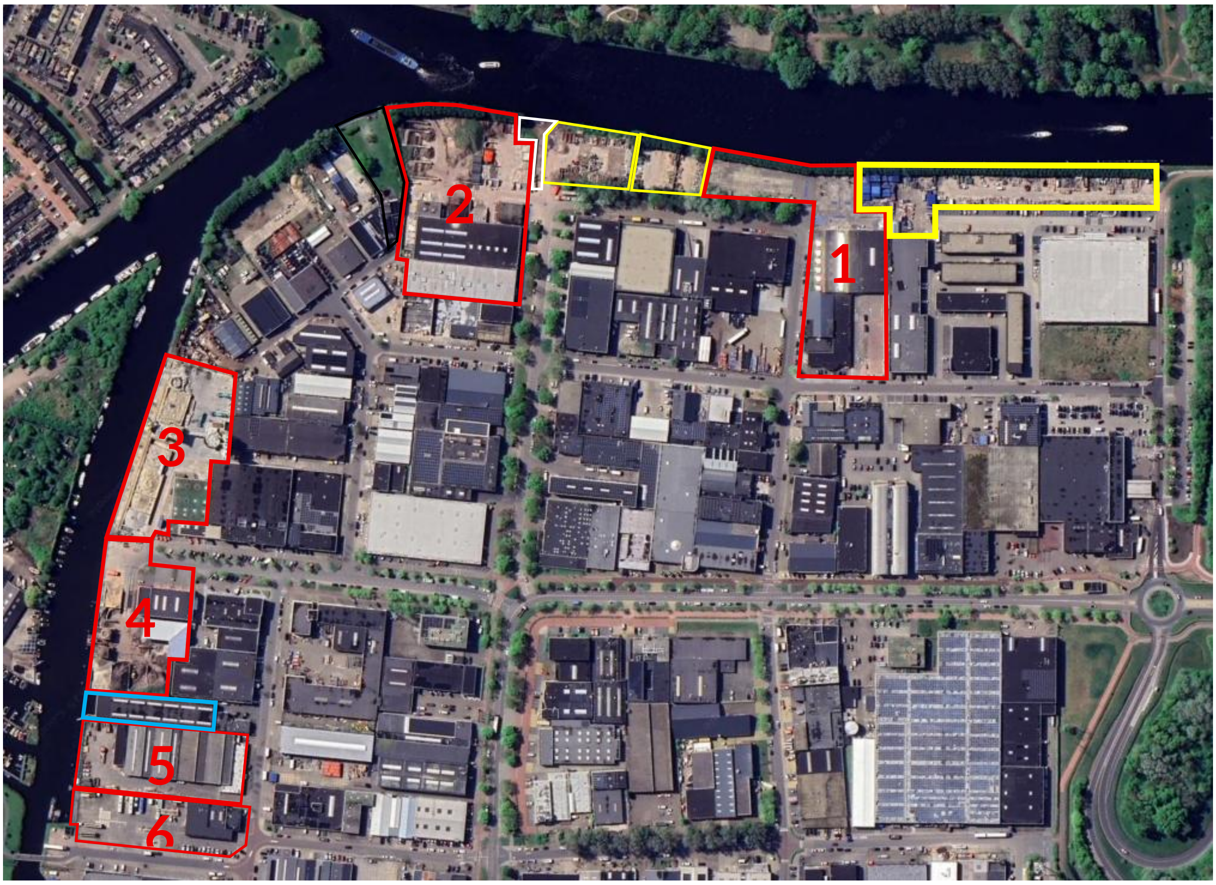

Figure 5-13: Heen Industry Park (Leiden)
Maps data: © Google | © 2025 Airbus

First, a building materials supplier, *BMN* (red #1 in Figure 5-13, more detailed view in Figure 5-14) has direct access to a lot of waterfront space, but with a lot of overgrown vegetation running between the site and the water. An array of unidentifiable storage areas along the waterfront can be observed (yellow in Figure 5-13), seemingly used for the storage of building materials (and thus, potentially, belonging to the building materials supplier *BMN*). However, these areas also have a lot of overgrown vegetation running along the waterfront which prevent immediate access to the waterway. Transhipment operations could be enabled in these areas by removing this vegetation – however, the underground below (i.e. the concrete of the quay itself) would have to be in a good state to allow for terminal equipment to operate, which is difficult to estimate without physical inspection on site. All of these areas seem to be well fenced off, which would allow for stricter control of the access to/from the site, including setting up a time-based configuration for access to certain hours of the day, if this is wanted.

Second, a sand and soil trader, *Jon Guyt* (red #2 in Figure 5-13) can be found with a lot of waterfront area. The last and southern-most unidentified storage area (towards the left in Figure 5-14) may indeed belong *Jon Guyt* and not *BMN*, but the story of the overall estate remains the same: space and access seem promising, but overgrown vegetation near the waterfront and a potential compromised underground as a consequence necessitate further investigation. There is a small area where the quay is not overgrown (marked with white in Figure 5-14), and which seems to be accessible. However, the general space is quite limited,

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which restricts the use of transhipment equipment and thus its applicability as a TPT. However, should transhipment equipment and storage facilities be waterborne, i.e. located onboard a floating platform or similar, as has been observed for other potential TPT locations within this analysis, then this area may potentially be useable as a TPT location if truck arrivals can be carefully planned so that the small stretch of road leading to the quay is not needlessly obstructed and/or congested. The access to the quay is mostly fenced off, however a gate is missing.

Figure 5-14 Waterfront storage areas as well as the BMN and the Jon Guyt premises
Maps data: © Google | © 2025 Airbus

Third, on the *Maandage Wetering* canal appendix, a cement contractor, *Heidelberg Materials* (red #3 in Figure 5-13 and available in detail in Figure 5-15, right side) is also located and appears already to be engaged in the transhipment of dry bulk materials such as sand and/or cement. However, given the location of the storage compartments on the quay itself, it seems unlikely that a container-based TPT application could be installed at this location unless money was invested in repurposing the existing bulk crane to also handle containers, in installing a new container crane or in creating a path for driving a reach stacker to the waterfront. All options would drive up CAPEX significantly and potentially make the TPT infeasible.

Fourth, next to the cement contractor is another location of *Jon Guyt* (red #5 on Figure 5-13 and available in detail in Figure 5-15, left side), which exhibits perhaps the most opportune location for a TPT concept in this area of Leiden. That is, outside of the location itself undertaking transhipment of dry bulk materials, noticeably soil, sand and earth-related materials, a large open waterfront area is located at the entrance to the site (marked in white on Figure 5-15). While the Jon Guyt premises itself is fenced off, the identified opportune quay for TPT deployment is not. While the area does not appear to be overrun with various irrelevant third parties or citizens, the potential safety and security risks that this pose may still be an important aspect that needs to be ensured. The accessible quay area seems to be around 30 meters in length (50 meters if the bulk storage compartments within the white mark on Figure 5-15 is removed), and a relatively recent upgrade of the infrastructure seems to enable it precisely to do transhipment of heavy cargoes vis-à-vis the Jon Guyt business of sand and soil. This indicates that heavy vehicles such as reach stackers etc. could begin operations here with relative ease. Other satellite imagery (see Figure 5-15 and Figure 5-16) also indicates that this investment may have been made in order to allow for two barges to attend the "terminal" simultaneously. This means that a TPT concept could relatively easily

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be deployed at this site, but coordination with the Jon Guyt facility must be ensured to safeguard that the quay is available for both operations in due time. The ongoing transhipment activities from between the storage compartments, marked in pink on Figure 5-15, might also provide insights into how reach stackers loading/unloading could be conducted on the terminal. The picture on the Jon Guyt website (click here) shows this activity in more detail: As the digger – wheeled, but with a platform that can semi-fix the vehicle to the ground – unloads the inland vessel, the cargo is immediately placed into one of the compartments on the quay (and vice versa). This means that the vehicles can remain fixed and unload the vessel efficiently. For a TPT concept, this will only be possible for the first few TEUs after which the transhipment area will be congested.

Figure 5-15 The Heidelberg Materials and the second Jon Guyt premises
Maps data: © Google | © 2025 Airbus

Figure 5-16: Satellite image of the Jon Guyt terminal with two inland ships moored alongside.
Maps data: © 2019 Google (left) | © 2021 Google (right)

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Figure 5-17 *Van Kempen Houthandel* and *Argos Jonker Katwijk* premises

Fifth and sixth, a buildings materials store, *Van Kempen Houthandel*, and a gas station, *Argos Jonker Katwijk* (marked in red #5 and #6, respectively, on Figure 5-13 and available in more detail in Figure 5-17). While these sites could potentially offer a larger quayside operational area for both transshipment and storage, the waterway interface is currently blocked by piles/pilings along the waterfront which seems to make waterway access to the site challenging. For these sites to be used, this waterborne access needs to be secured by e.g., removing obstacles that may obstruct the vessel from mooring alongside the quay. This is another important aspect that should be included in the development of the TPT concept: waterborne accessibility for inland vessels. Should this be safeguarded, the sites offer around 50 and 25 meters of quay length, respectively, which makes the latter site (i.e. the gas station) particularly difficult for the AUTOFLEX CEMT II vessel to visit. However, an adjacent area and quay (see top left corner of Figure 5-17) could potentially itself be a TPT terminal with around 40 meters of quay length (split across two quays) and a total surface area of ca. 450 m^2. As can be seen in the photo, this would allow a truck to be positioned with the back towards the water so that units can be loaded directly onto the truck trailer for it to drive off into the hinterland. At the same time, however, the width of the waterway near this "adjacent quay" site is merely 15 m. in length, which makes vessel maneuverability significantly restricted. However, this location may be more of hypothetical possibility than of realistic applicability.

Lastly, a shipyard is available in the area (marked blue in Figure 5-13) which could potentially offer various maintenance services for the AUTOFLEX CEMT II vessels that would call this industrial area. However, this is also interesting for the purposes of TPT. That is, is there a way in which shipyards can be used as transshipment sites whenever they are not in use for maintenance purposes? While the idea is interesting, it may face an array of operational and commercial issues. Ship maintenance is often less predictable, with ships entering shipyards as a result both of routine maintenance and impromptu repair based on faulty equipment etc. With regards to the latter, this may mean that the availability of this site may be rather sporadic and unpredictable, which does not align well with timely and reliant logistics needs. Regardless of whether shipyard or transshipment activities prove more commercially profitable in this case, it leaves a complicated web of coordination between the two services that must be carefully aligned so that repair-based services can still be offered without compromising the transshipment potential (and vice versa). Nevertheless, the idea of converting shipyards into multiuse sites that engage in both repair and transshipment services may be an interesting line of enquiry for the TPT concept. As can be seen in the Google Street View image by clicking here, there are already cranes and hoisting devices available at the site, which could potentially be converted and/or outfitted with container-carrying modules.

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5.3.3.2. LEIDEN AREA 2: RIJN CANAL NORTH WEST OF CITY CENTRE

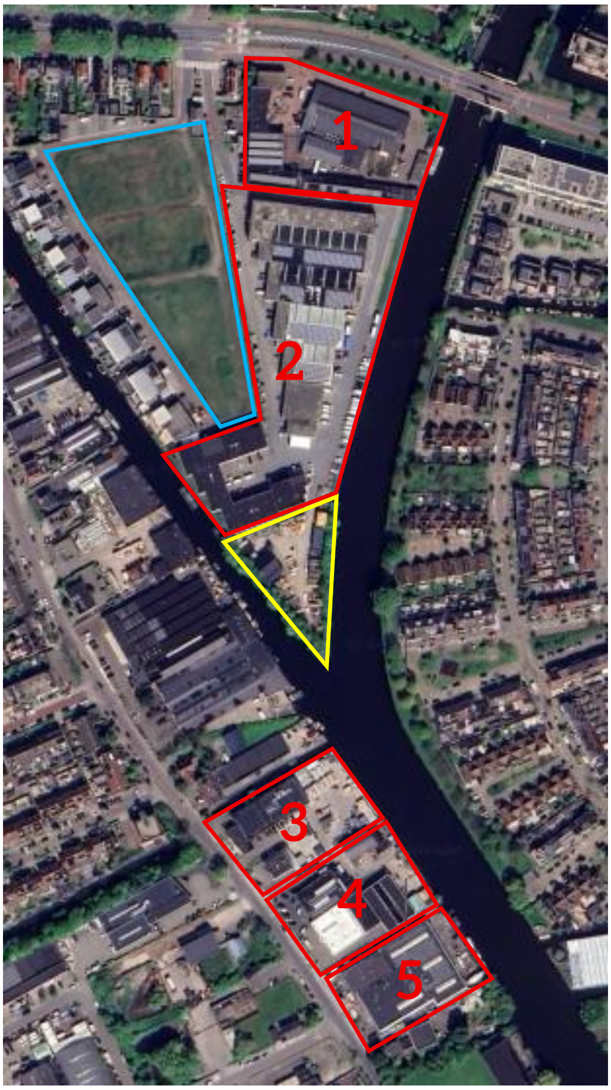

Figure 5-18 Area #2 of Leiden
Maps data: © Google | © 2025 Airbus

Moving further along the *Rijn* canal in Leiden, another industrial area can be found (Area #2 in Figure 5-12) with a few points of interests as can be seen in Figure 5-18. This area consists of two locations with various smaller businesses (red #1 and #2), three individual businesses along the waterfront (red #3, #4 and #5) and an unidentified storage area (yellow) – all of which seems to have a hard waterfront. Furthermore, a large brownfield (blue) is present right next to location #1 and #2, which could potentially be developed into a storage area extension for any TPTs developed in this area, especially for the red #1 and #2 sites.

The first site with smaller businesses (red #1) has, amongst other things, a smaller boat repair shop, with the main office located directly next to the waterway. A more granular view of this location can be found to the left in Figure 5-19. Combined with general overgrown vegetation near the waterfront, this location does not seem suitable for TPT concept developments because of the restricted space around the quay upon which cargo handling equipment should operate. Furthermore, installing a larger cargo crane seems an abnormally high CAPEX given the general small size of the location and the lack of a single dominant modal shift customer who could ensure sufficient cargo throughput. While this does not mean that the location is unusable, as multiple smaller actors could unite around the TPT concept, it generally makes the application challenging due to potential coordination and orchestration issues between the smaller actors combined with the general small space available. In sum, given that multiple parameters may be compromised, it makes the location less opportune for a TPT concept deployment.

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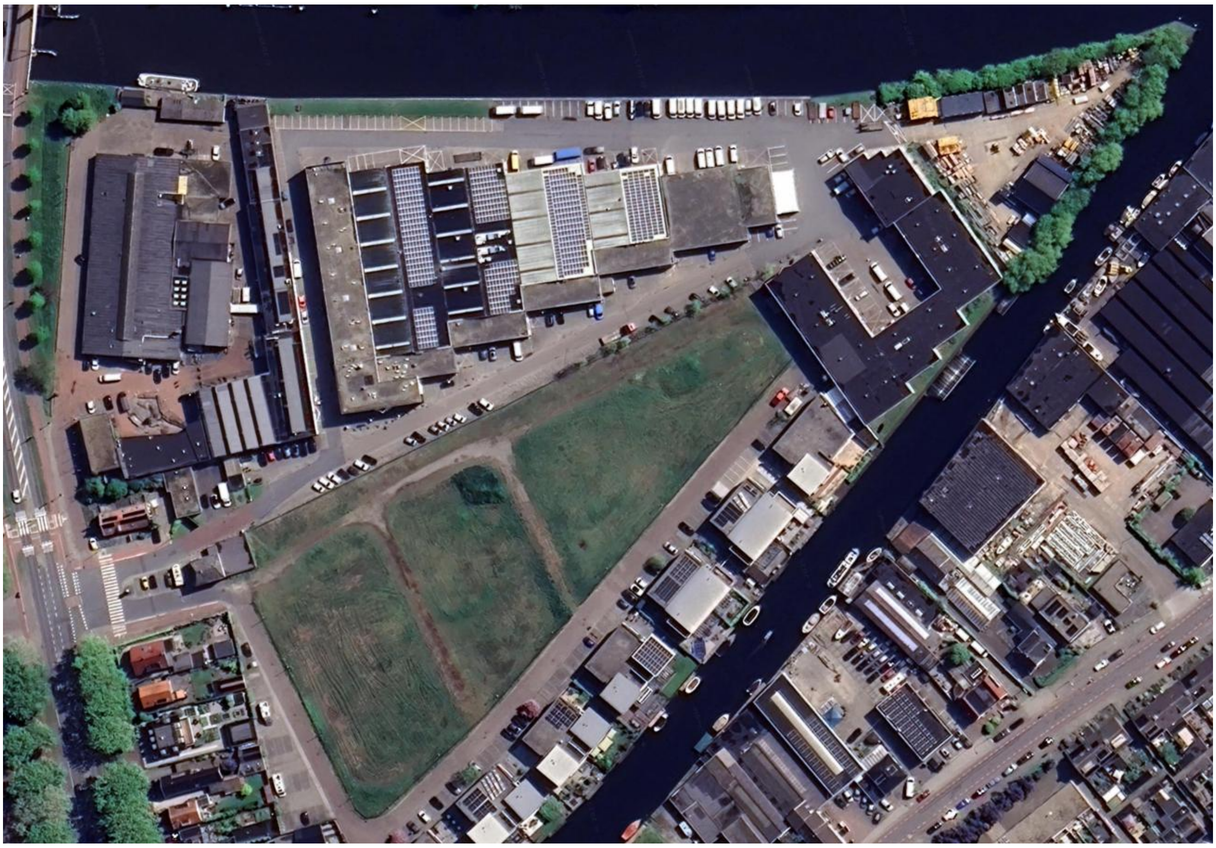

Figure 5-19: Location #1 and #2 in Area #2 of Leiden
Maps data: © Google | © 2025 Airbus

Second, the other site with smaller businesses (red #2 in Figure 5-18, and in more detail in Figure 5-19) has a hard waterfront with a modest amount of overgrown vegetation and with a parking area for its current tenants. On first impressions, this site seems much more applicable to a TPT concept than the previous. However, this would require relocating the waterfront parking area elsewhere to allow for cargo handling equipment to operate on the quay safely. Should this be possible, the immediately available quay is around 95 meters in length, which would allow for multiple AUTOFLEX vessels to call the site simultaneously. Should the current area with overgrown vegetation be tidied up and cut down, the quay could be extended to a total of approximately 160 meters. The site does not have any immediate storage space available (for cargo units) that would not interfere with the current operations of the businesses on the site. However, as mentioned, a larger brownfield is available adjacent to the site, which could potentially be developed. This brownfield is around 1 ha (i.e. 10.000 m^2) in size and from historical satellite images, it does not appear to have been developed at any point in time. This could indicate that it is being used as it is, potentially by the local residences. Hence, interviews with the local businesses and residences must be conducted before determining if the area can be used as a storage extension to the potential TPT concept at this site – including if all or parts of the field could be repurposed. Furthermore, the adjacent unidentified storage area (yellow in Figure 5-18) could potentially also be used as the storage elasticity (either as substitution or addition to the larger brownfield), although this would require deeper insights into how the storage area is used today. While road-borne access is somewhat restricted, a circular one-way direction road could potentially be set up to avoid multiple vehicles passing each other simultaneously. The area is closed off by the layout of the buildings themselves creating a natural barrier to access combined with actual fencing along the perimeter with the brownfield, and with a designated gate that monitors and

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controls access to the site. If the brownfield is to be developed and used for storage, and access control is needed, fencing would have to be added around the brownfield, if not already available.

Third, three potential TPT locations (marked as red #3, #4 and #5 in Figure 5-18) can be found: a contractor, *Van Rhijn* (#3), an auto repair shop, *Autobedrijf Stipdonk* (#4), and a water sport and boat repair shop, *Maritime Center Rijnzicht* (#5). These can be seen more in detail in Figure 5-20.

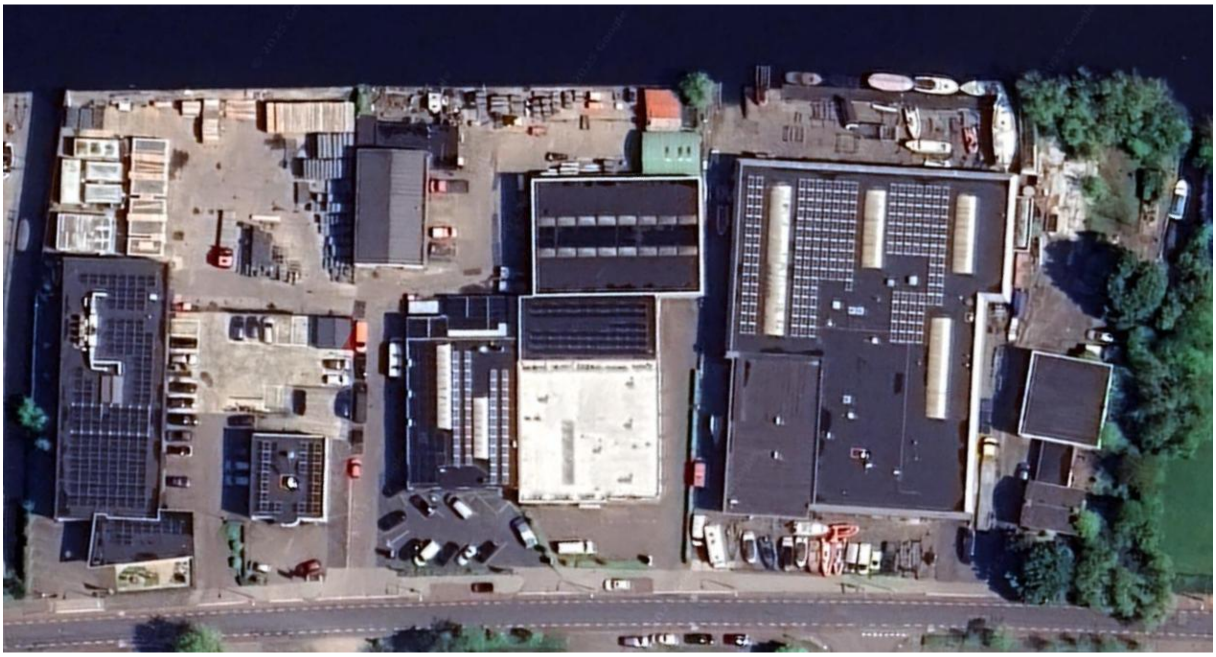

Figure 5-20 Location #3, #4 and #5 in Area #2 in Leiden
Maps data: © Google | © 2025 Airbus

The first of these locations, the contractor *Van Rhijn* (#3), seem to use the waterfront as a storage area for the company's various building materials used for the purposes of its contracting services. While the site may potentially be reorganised to keep the waterfront clear and the quay available for cargo transhipment purposes via a TPT, one must necessarily consider how the contractor would be able to store these building materials alternatively. That is, however, not to say that this would be an impossible task, but it must be done with utmost care towards the daily operations of the site today. Should this be possible, the site has ca. 50 m of immediately useable quay length, and an overall operational area of ca. 1.800 m^2 on the waterfront. Access seems relatively easy, although the narrow entry-path would not allow for simultaneous entry and exit to the premises. Inspecting Google Street View, it also appears that fencing and a gate is already in place.

The second of these locations, the auto repair shop *Autobedrijf Stipdonk* (#4), seem to have the exact same conundrum as *Van Rhijn* – albeit more exacerbated due to its smaller operational area. While the potential quay is ca. 60 m long and seem to me more or less immediately useable, it is largely saturated with storage of various materials belonging to the auto repair shop. Furthermore, the operational area near the waterfront is ca. 600 m^2, which should theoretically be sufficient to conduct transhipment activities, the characteristics of the operational area seem to be such that accessibility is poor with very limited turning space for last mile vehicles, resulting in a potential congestion/bottleneck issue at the premises. The layout of buildings implies that minimal additional fencing and a gate would be needed if access restriction should be needed.

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The third and last of these locations in the area, the water sport and boat repair shop *Maritime Center Rijnzicht* (#5), seems not to be adaptable to a TPT concept given its poor accessibility, its crowded waterfront and, assumingly, its general need to use waterfront for business activities related to its functioning as a water sport and boat repair shop.

5.3.3.3. LEIDEN AREA 3: RIJN CANAL WEST OF CITY CENTRE

The third potential Modal Shift Opportunity Area (MSOA) in Leiden (Area #3 on Figure 5-12) can be found in a smaller industrial area a little west of the city centre. The area can be split into two based on its current use, as visualised in Figure 5-21: one end consists of a group of smaller garages and car dealerships (blue) while the other end consists of a boat and barge rental company (yellow). While the former zone is deemed unfit for a TPT concept due to the same issues as those identified in Area #2, locations #3-#5, of Leiden (see Figure 5-20 and associated text), the latter zone calls for more thorough investigation of its potential suitability vis-à-vis a TPT concept. Thus, a more granular view of the premise is available in Figure 5-22.

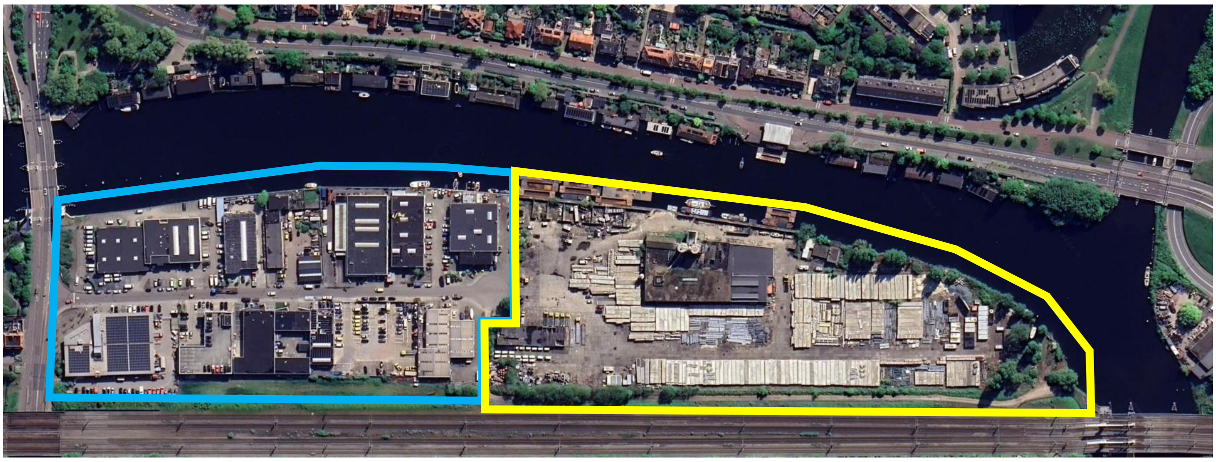

Figure 5-21 Area #3 of Leiden
Maps data: © Google | © 2025 Airbus

First, one will notice that there are already barges moored alongside the waterfront (perhaps not surprising given the services provided at the location), which indicates that there are ample mooring facilities available. However, this may also indicate that the site is familiar with and actively deploying floating storage facilities in some shape or form. That is, using floating barges and/or platforms as the storage facility for the TPT. Second, the current satellite imagery of the location indicates that there is a lot of container-like units stored on the premises. While it is unknown what these units are used for, it indicates that there may be storage option on the premises also. While there is no onshore cargo handling equipment visible, it does not seem farfetched to imagine such equipment, e. g., reach stackers, operating on the terminal. However, intuitively, there does not seem to be a lot of space currently available near the waterfront as a potential transhipment area. This may compromise the relevance of the site as a potential TPT site. A potential solution here could be to remove the waterfront storage compartment (top left area in Figure 5-22) and use this area for the transhipment of cargo. Alternatively, the waterfront greenery (right side of the image) could be removed, but the underlying pavement may potentially be damaged and not immediately suitable for heavy machinery. Even more alternatively, transhipment could be provided by a floating barge and/or platform, similar to the existing barges and their potential use as storage extension to the terminal. In this way, minimal space would be needed shore side. The area is fenced off, with a gate at the entrance to the left in Figure 5-22, implying that safety and

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security in terms of access restriction is already in place. All-in-all, all three transhipment options seem plausible and, in general, the location seems relevant for TPT purposes.

Figure 5-22: The potential TPT location in Area #3 of Leiden
Maps data: © Google | © 2025 Airbus

5.3.3.4. LEIDEN AREA 4: THE WATERWAY INTERSECTION BETWEEN OUDE RIJN & RIJN-SCHIEKANAAL

The fourth potential TPT location area in Leiden (Area #4 in Figure 5-12) can be found at the intersection between the two waterways *Oude Rijn* and *Rijn-Schiekanaal* to the east of Leiden. Here, one can find two larger subareas (highlighted as #1 and #2 in Figure 5-23) belonging to the *De Waard* district (in *Leiden*) and the *Zijlkwartier* district (in *Leidendorp*) respectively.

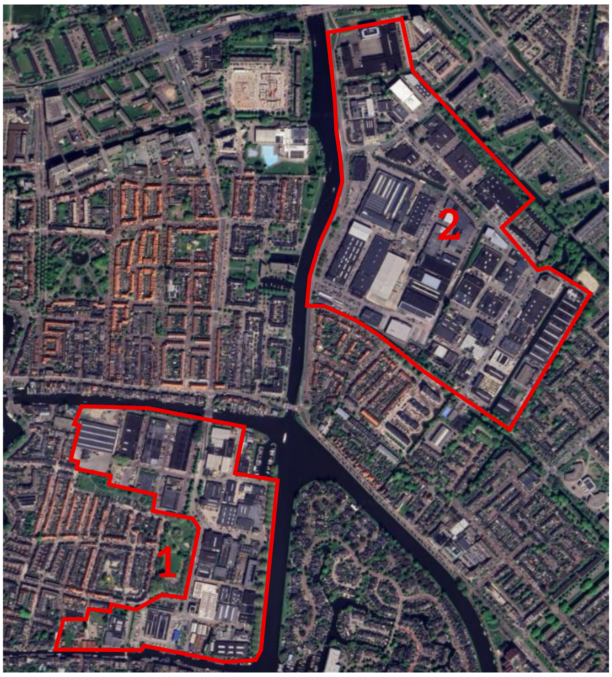

Figure 5-23 Area #4 of Leiden
Maps data: © Google | © 2025 Airbus

To start with the lower most area (i.e. area #1 in Figure 5-23), one finds an industrial area with a few wholesalers, retailers etc. Granted, when inspecting the potential transport customers in this area, it does not seem that they are perfect candidates for modal shift efforts. That is, while the location includes a few entities such as the "Urban Management" department within the Municipality of Leiden, a transport service provider and a lumber store, the remaining companies seem to either be too specialised or too small to be interested in waterborne transport solutions (unless they could potentially book part loads in a container). As can be seen from the satellite image (Figure 5-24), most of the waterfront is overgrown with foliage, making the majority of the locations suboptimal for TPTs. This is amplified by

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the proximity of the buildings to the waterfront itself, which limits space for potential transhipment activities. However, a few points of interests stick out and have thus been marked on Figure 5-24: a municipality department (red #1), neighboured by a shipyard (red #2) and a lumber store (red #3). Also, two smaller quay sites have been observed (yellow), which could potentially be used also.

Figure 5-24 First subarea in Area #4 of Leiden
Maps data: © Google | © 2025 Airbus

Beginning with the "Urban Management" department within the Municipality of Leiden (marked as #1 in Figure 5-24 and depicted at higher granularity in Figure 5-25), the area has a solid waterfront that seems to be in a decent state, with no immediate obstacles at the waterfront that would limit transhipment operations. Furthermore, there seems to be ample space both for transhipment and for subsequent storage – particularly to the right side of the main building vis-à-vis Figure 5-25 (left). There are predominantly two quay areas on the premises, both of ca. 40 m in length: a "right-angled" quay in the upper left corner of the premises, and an "oblique" quay directly above the main building. While both of these quays are currently used for parking, this parking could potentially be relocated to allow for this space to be used for transhipment purposes – or, potentially, arranging the operations such

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that the parking is used for the “Urban Management” department themselves during the day or in weekdays, and for cargo transhipment purposes during night or on weekends (when the staff of the department could be expected to not be present at the premise). This may be relevant also in light of that the “Urban Management” department themselves may not be in need of transport services over water, but that they could enable some of the adjacent businesses in doing so by offering their location as a TPT during the weekends, when the building and/or area is not otherwise used for the purposes of “urban management” within Leiden. The area is fenced off and access could thus be strictly controlled to allow for such operation.

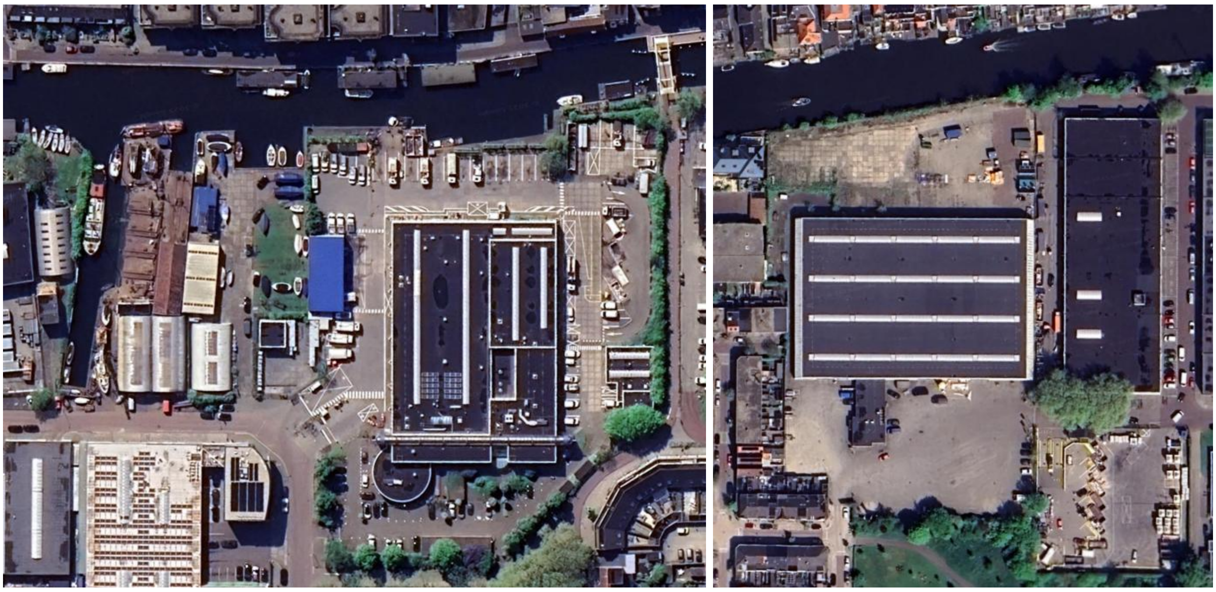

Figure 5-25: Left: Urban Management department of the Municipality of Leiden (#1) and the next-door shipyard (#2), Right: The Leiden north lumber store (#3)
Maps data: © Google | © 2025 Airbus

Continuing to the lumber store, as depicted in Figure 5-25 (right), one finds another potential TPT location. The waterfront has some minor overgrown foliage that must be removed to ensure proper transhipment operations. However, this is deemed a minor task, particularly compared to other potential TPT sites within this analysis. The location shows a large operational area both in front of and behind of the lumber store building, which indicates ample space both for transhipment operations and general storage. That is, the quay is ca. 100 m in length, potentially allowing for multiple AUTOFLEX vessels to visit the premises simultaneously, while the quayside operational area, e. g., for transhipment purposes, is ca. 4.000 m^2. While it does not look like there is an immediate easy access path between these two sides of the building, which would compromise the seamlessness of the operations here, it may be that vehicles can pass through the building, in which case the access would be rather convenient (depending on the overhead clearance for trucks on the path within the building). Potential cargo handling equipment and terminal equipment of various kinds could be stored in the main building and could be used either on-demand throughout the day when the lumber store is open, and/or at night or on weekends, whenever the lumber store is closed for the public. Adjacent to the lumber store is also a smaller parking space, marked in blue on Figure 5-24 and visible on the lower right of Figure 5-25 (right). This area seems to already be used for storage of various kinds, including the odd container. While it is unknown whether this belongs to the lumber store estate, it seems unlikely that the lumber store would need additional storage given the otherwise rather vacant areas within its own premises. If activities are aligned with this area, transport units could potentially be placed in this area

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and picked up without interfering with the operations of neither the lumber store nor its TPT operations. Given its controlled access, this area could be used for industrial cargoes in similar vein to how urban parcel collection systems work. Disconnecting the pick-up/drop-off activities with the transhipment activities and, potentially, otherwise day-to-day activities of the lumber store may be a way to avoid congestion and optimise service efficiency. This creates an asynchronicity that could offer a lot of flexibility to the TPT operations.

Figure 5-26 Two potential transhipment points in Area #4 of Leiden
Maps data: © Google | © 2025 Airbus

In addition to these two sites, a couple of potential transhipment points can be found without any immediate connection to any industrial site. These are marked with yellow marks in Figure 5-24 and can be seen in a more granular depiction in Figure 5-26 (satellite photo) and in Google Street View (northernmost here and here, southernmost here). While both the quays seem to be long enough to accommodate the AUTOFLEX vessel and are relatively undisturbed by overgrowth or similar, it is difficult to imagine how they may effectively be used vis-à-vis the TPT concept due to the limited quay (apron) space. Potential water-based constellations may circumvent this issue, such as utilising water-based cargo handling, storage and mooring solutions as a temporary quey extension.

The southernmost of these locations (left on Figure 5-26) has the longest quay of ca. 90 m. in total. However, the width of the quay on ca. 2/3 of this length is merely 3-4 meters and does only have access from one end. This would not allow for cargo handling equipment to execute their designated transhipment actions as the vehicles would likely not be able to turn – unless a larger, fixed cargo crane was erected, or the quay apron was extended, which however would significantly run up to CAPEX of the TPT and likely, if not certainly, financially implausible. Alternatively, a waterborne cargo handling equipment solution could potentially be moored alongside the premises and help with transhipment operations in a manner that would not require larger operational areas shoreside. This is how the site has historically been used for transhipment purposes (see Figure 5-27). At its wider sections, i.e. the remaining 1/3 of the quay, the width is around 13-15 m. and is already used for what appears to be garbage containers. Given that a 40" container is ca. 12.2 m. long (i.e. 40 foot), this may allow for containers to be stored at a right angle to the quay. This would matter because it would potentially allow trucks to pick up the containers for last mile transport more conveniently than if the trucks were to reverse into the narrow part of the quay (and risk tipping into the canal). This is also how the majority of containers are placed on the site today (see Google Street View here). Thus, this location may provide inspiration towards a TPT storage solution that sees containers positioned such that last mile trucks can conveniently take them away. The location is not fenced off, so if access restrictions would be needed this would have to be established. Which appears to be challenging due to the parallel road and limited space for transhipment operations; fencing off the quay would further limit the space.

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Figure 5-27 Historical images of the southernmost (left) and northernmost (right) transhipment site (vis-a-vis Figure 5-26).
Maps data: © 2020 Google | © 2018 Google

The other, northern most, location (right on Figure 5-26) has a similar conundrum and potential solution space. The quay is ca. 90 m. long, of which only ca. 25 m. are not overgrown. The potential operational area near this quay is 10-12 m wide throughout the quay's length. From Google Street view analysis (click here), it appears that the space is exclusively used by the adjacent demolition contractor, *Van Eijk Leiden*, as a parking area for their various vehicles etc. From historical satellite images (see Figure 5-27, right), it appears that the demolition contractor is regularly using the site to tranship materials over the water, assumingly materials related to demolition services such as building waste of various kinds. As also seen on the other transshipment sites, containers and trailers are positioned at a right angle to the quay (or at least somewhat of a right angle), which would allow both for trucks to be loaded/unloaded directly into their cargo holds/trailers and for containers to be positioned such that when they need to be moved unto a truck, the truck would have better access to the container such that it can more conveniently reversed towards the container without having to go through more complex turning manoeuvres etc. Unlike the previous transshipment site, a smaller potential storage area can be found which makes up ca. 50 m^2. Access restriction to this location could potentially be solved by setting up a gate across the access road (directly south of the location, see Figure 5-24).

If we continue to the other subarea of area #4 in Leiden, one finds an array of industrial points of interest, including, amongst others, a shopping mall, various furniture retailers, PostNL, and many smaller car and fashion retailers.

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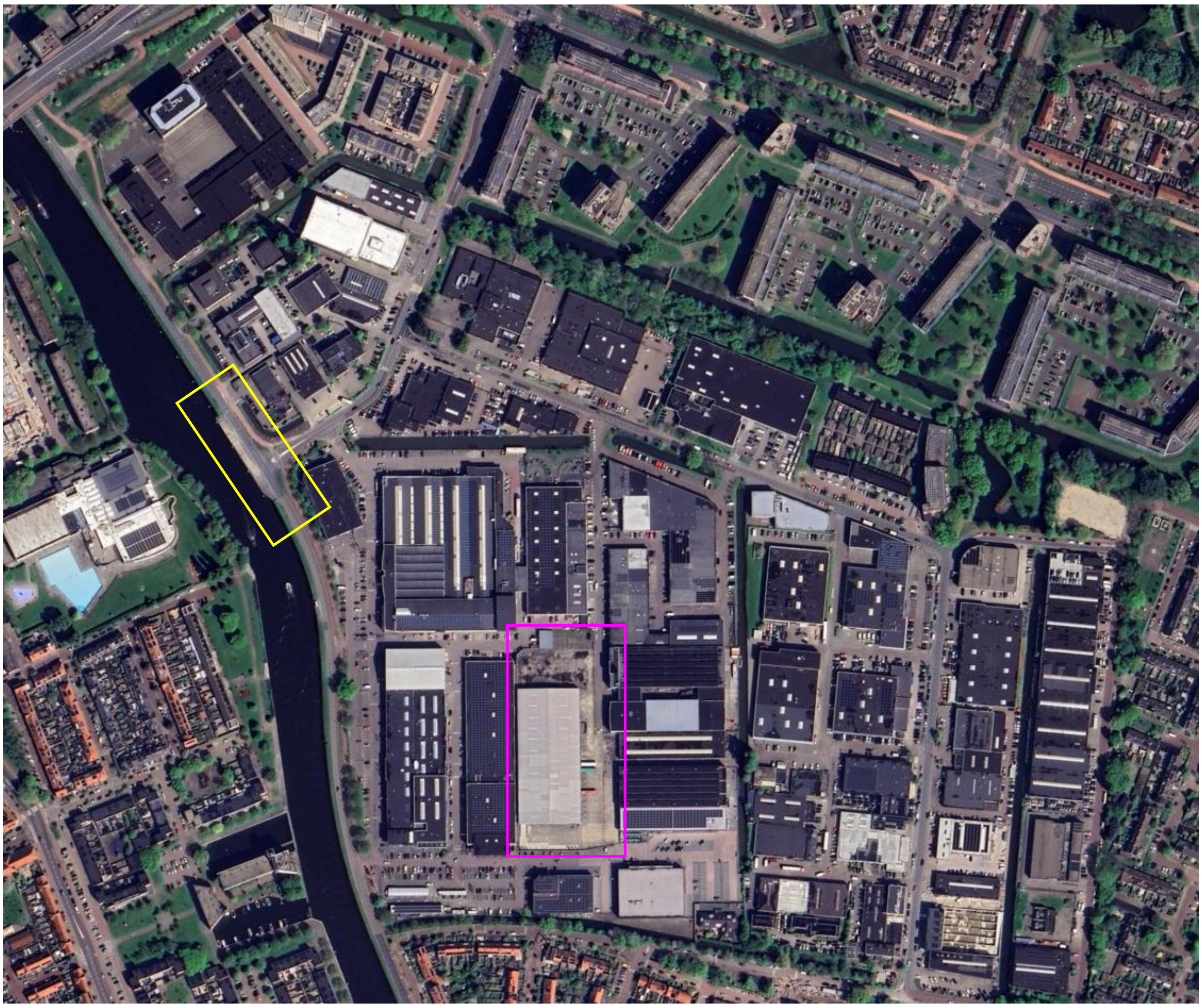

Figure 5-28: The *Zijlkwartier* district in Area #4 of Leiden
Maps data: © Google | © 2025 Airbus

A public road runs along the waterfront of the area, cutting off the industrial area from immediate access to the waterway. Only one smaller area has developed waterfront infrastructure on the waterside of the public road, marked in yellow on Figure 5-28 and given in more detail in Figure 5-29. However, as seen in Google Street View by clicking here and here, the quay has been used for cargo transfer in recent years, indicating that it has the potential to serve as a TPT location. Notably, the fencing used during cargo transfer is simple, lightweight, and is still present in the street view images available to date, indicating that the quay is still possible to use for cargo transfer (at least under the same format as it has been used previously). Space for storage is limited at the quay, which might imply that the number of containers transferred at this site could be small. However, PostNL cargo services is located across the road (marked in pink on Figure 5-28), which could be a potential customer of the AUTOFLEX transport

Figure 5-29 Quay in the *Zijlkwartier* district (Area #4 of Leiden)
Maps data: © Google | © 2025 Airbus

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service. Furthermore, the PostNL cargo services has an area on the north side of the distribution centre which is seemingly unused and could serve as the storage location for a TPT located here.

5.3.3.5. LEIDEN AREA 5: ZOETERWOUDE-RIJNDIJK ON THE OUDE RIJN

The fifth and last TPT Opportunity area around Leiden (Area #5 in Figure 5-12) lies just east of the city in the village of *Zoeterwoude-Rijndijk* – a location of particular interest given that a large Heineken brewery lies here with its associated distribution centre and offices. In addition, a cluster of various smaller companies and a few logistics centres can be found to the west of this large Heineken complex (see Figure 5-30). Inspecting the waterfront locations more in depth, one finds that transhipment activities and IWT services are already present – however, exclusively in a dry bulk form, it appears. Starting from the left, vis-à-vis Figure 5-31, we have identified four locations worth further investigation.

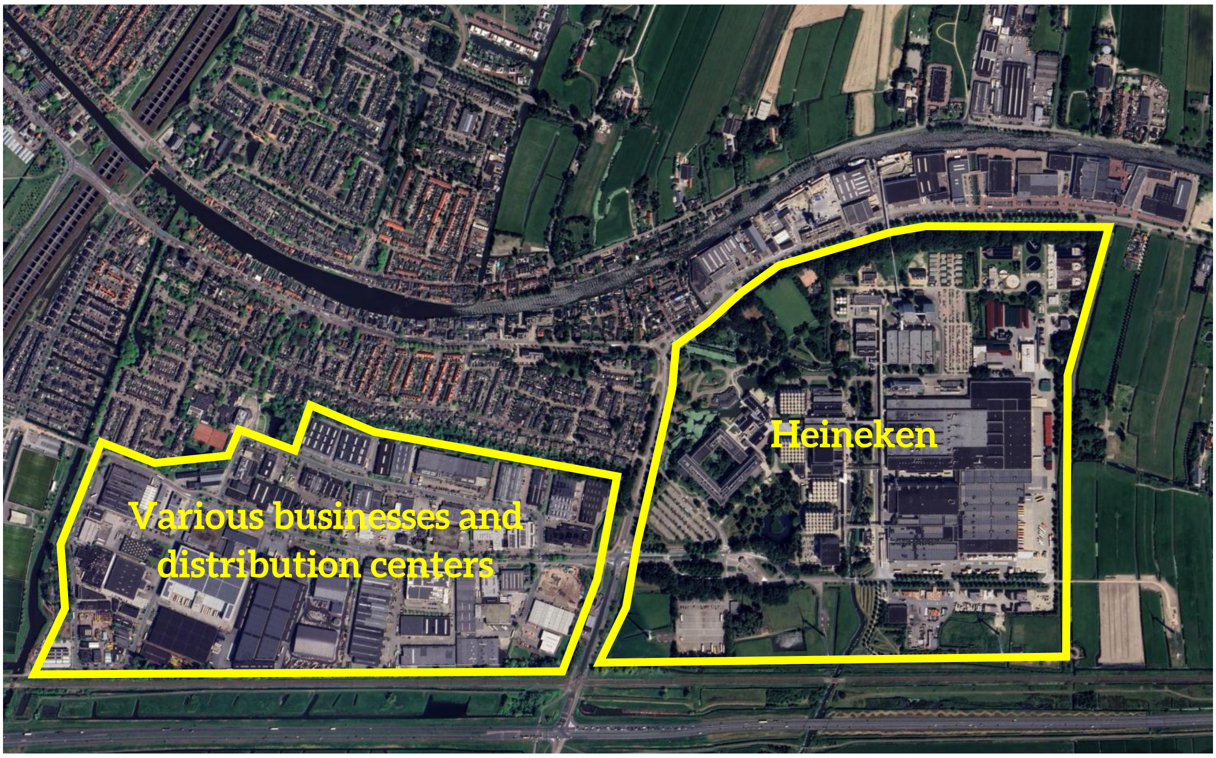

Figure 5-30: East of Zoeterwoude-Rijndijk
Maps data: © Google | © 2025 Airbus

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Figure 5-31: Waterfront at Leiden Industrial area #4
Maps data: © Google | © 2025 Airbus

First, a cement contractor can be found with an active transhipment-enabled waterfront, see top left of Figure 5-32. While this location could potentially be reformed into a TPT, the presence of large cement storage units near the quay and the limited available space for transhipment equipment, such as a reach stacker, on the quay itself, makes the location poorly adaptable to TPT operations (unless the cement storage units are relocated). However, as this is deemed to directly interfere with the ongoing operations and activities of the terminal, namely dry bulk shipping of cement, the analysis concludes that this is not a realistically interesting TPT location.

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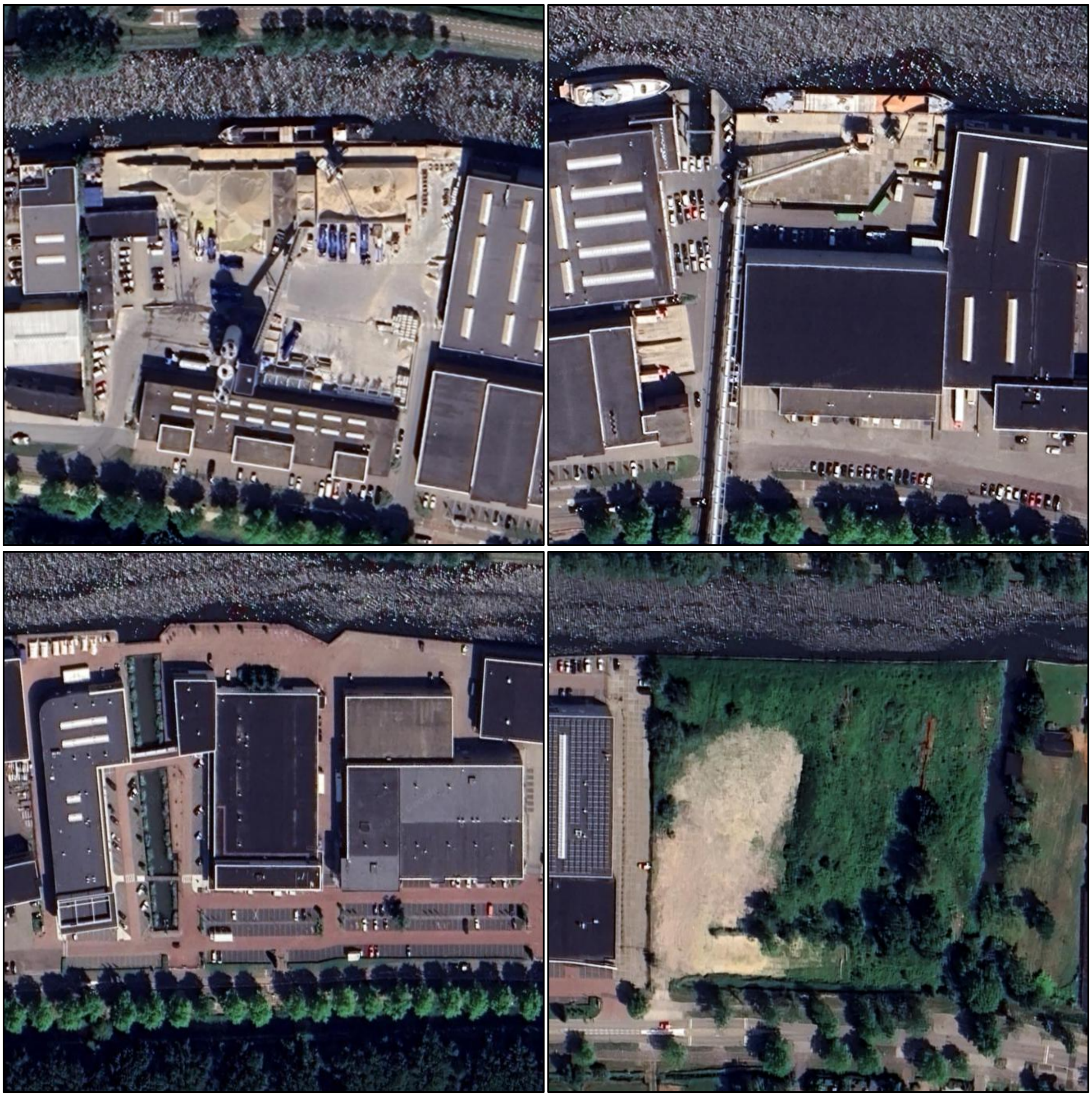

Figure 5-32 Top, left: Cement contractor | Top, right: Heineken and Rijneke Logistics | Bottom, left: Shopping centre | Bottom, right: Brownfield.
Maps data: © Google | © 2025 Airbus

The other "active" terminal in the area appears to be a shared location between the Heineken complex and Rijneke Logistics, a transport provider, see top right of Figure 5-32. A cargo pipe runs from the terminal and into the Heineken complex, used for transporting the incoming grain-based dry bulk from the terminal to the Heineken brewery. Below the pipe is a road that provides access to the terminal itself. The presence of an overhead structure compromises its TPT relevance, as it becomes difficult for e. g., reach stackers to lift and move cargo efficiently without the risk of colliding with the pipe. This, combined with the general limited space, makes a TPT concept difficult at this site.

The third location with TPT potential is the waterfront of a smaller shopping centre, see bottom left of Figure 5-32. While the area is immediately accessible by the public today, this might compromise security and safety requirements and should be addressed to allow TPT operations here. However, if solved, the location has ample space to allow for transhipment

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operations, but with limited storage area for containers etc. This could be circumvented by using floating storage solutions, as seen elsewhere.

The fourth and last location with TPT potential in *Zoeterwoude-Rijndijk* relates to a brownfield that appears to be under development (see bottom right of Figure 5-32). The area is fenced off, allowing for controlled access, and has easy access to a larger road. It is around 1.5 ha (15000 m2) in size and could potentially be developed in collaboration with the adjacent Heineken complex to offer container-based transport of canned/bottled beer from this location to the Alphen an den Rijn terminal (a trip that Heineken is performing today via the road) for consolidation unto Rotterdam.

5.3.4. MSC CLUSTER 4: DEN HAAG / DELFT

The fourth and final sub-area of WAC1 encompasses the broader Delft and Den Haag region; a geographically dispersed industrial landscape where potential waterfront logistics sites vary markedly in scale, accessibility and functional maturity. Although Delft and Den Haag are officially distinct municipalities, the industrial zones surrounding them form a near-continuous corridor of commercial and logistical activity, with no clear functional boundary between the two urban areas. For the purposes of this report, it was therefore both practical and analytically coherent to approach them as a single, integrated study area, as the spatial and operational characteristics relevant to TPT deployment consistently transcend municipal borders.

Unlike the more concentrated clusters studied in earlier sections, this zone is characterised by a patchwork of industrial pockets – some of which are centrally embedded within dense urban fabric while others are located along peripheral canals or within evolving business districts. This decentralisation introduces both opportunities and structural challenges for the feasibility of TPT concept, particularly regarding space constraints, public–private interface complexities, and the operational reality of existing waterfront uses. The following sections therefore explore six distinct areas in detail, assessing their suitability for waterborne transhipment and logistics innovation. The six areas are marked in Figure 5-33 by numbered yellow circles.

There is one area, marked by the pink circle in Figure 5-33, which might appear promising for applying one or more TPTs. The industrial sites and logistics actors found in this area are somewhat scattered, but they are near the waterways, seemingly accessible for an AUTOFLEX transport service. The challenge, however, is that access to this area is via the canal heading North-West from area 2, which is crossed by a fixed bridge that restricts vessel height above water to 2.93 meters. Meanwhile, the ATUOFLEX vessel is designed to have a battery container on the poop deck, causing its height to be in the range of 3.82 to 4.99 meters, depending on carried weight. It is possible to place the battery container within the cargo hold, which reduces height to be in the range 2.52 to 3.22 meters, for full containers and empty ship respectively. However, that implies that cargo capacity is reduced to 10 TEU, and that the vessel can only pass this bridge if it carries enough weight. To make matters worse, there are other bridges in the area marked by the pink circle ,which currently are not defined in EuRIS [14]. These bridges could potentially block access completely. Since restricting the vessel

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capacity will compromise the business case, and due to the possible infeasibility of accessing canal sections near customers, this area was not investigated further.

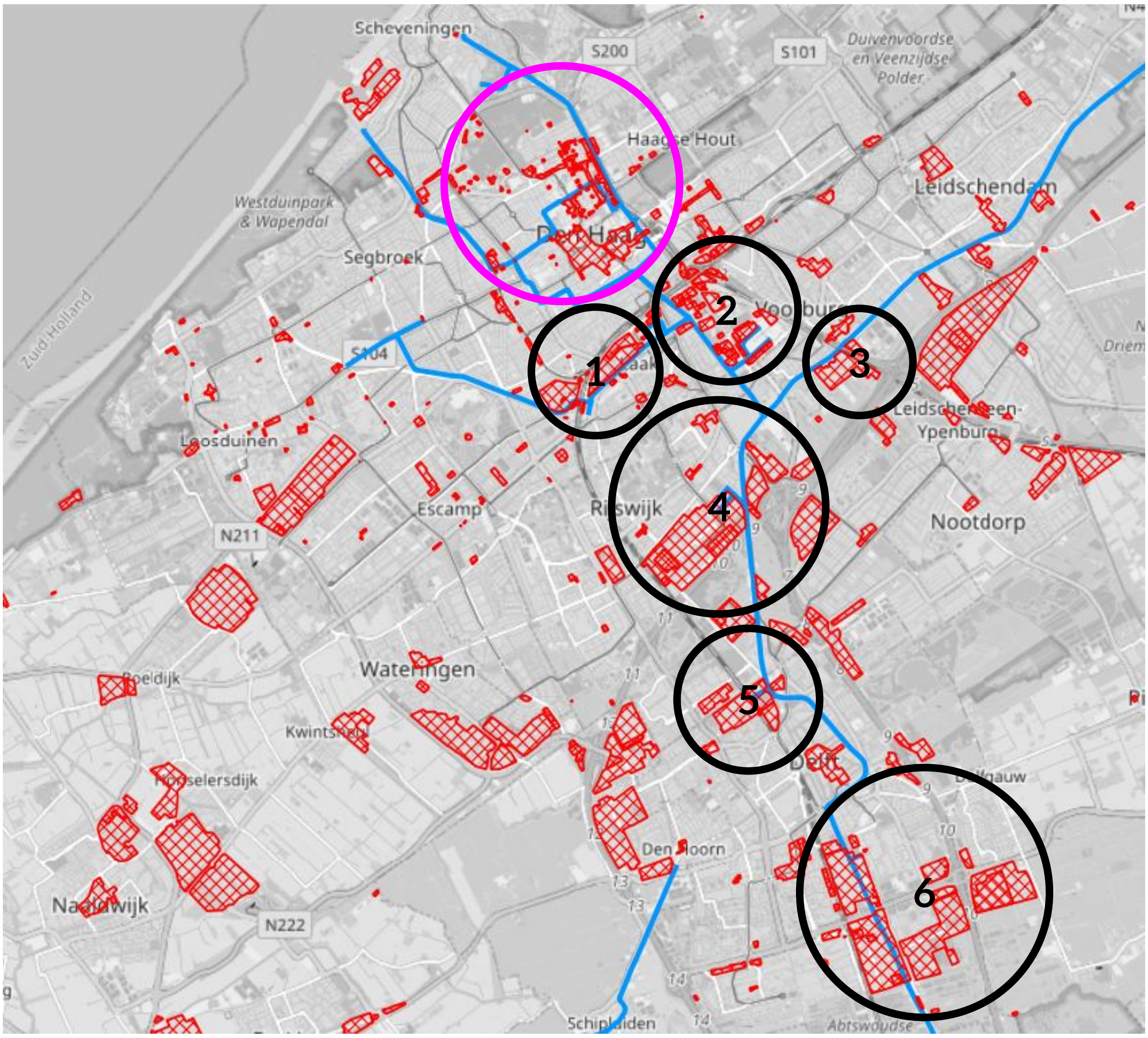

Figure 5-33 Industrial area(s) of Den Haag and Delft
Maps data: © OpenStreetMap| © EuRIS

5.3.4.1. DEN HAAG / DELFT AREA 1: LAAKHAVEN

A particularly prominent site in the more central area of Den Haag is the former *Petroleumhaven* in the *Laakhaven* district. This can be seen in Figure 5-34. Historically, the *Petroleumhaven* functioned as the city's key hub for oil imports and storage throughout much of the 19th and 20th centuries, forming an integral part of the city's industrial waterfront. As oil-related activities were progressively relocated away from the urban core due to reurbanisation pressures, the site lost its original function and gradually fell into a state of not being used. Today, the area (now also referred to as *De Havenmeesters*) is in the process of being redeveloped into a mixed residential and commercial district, the development plans are found here, with new buildings being erected directly along the waterfront (Figure 5-34 top image is from 2023, bottom from 2025). While the Petroleumhaven, in its current transitional

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state, could theoretically present an interesting opportunity for a TPT deployment, the already ongoing redevelopment trajectory significantly constrains such a possibility.

Figure 5-34 Petroleumhaven in Laakhaven, Den Haag
Maps data: © 2023 Google (top image) | © 2025 Airbus (bottom image)

The planned proximity of residential and commercial buildings to the quay suggests that future transshipment activities would be spatially, operationally, and socially challenged with the envisioned urban blueprint. Although the site could in principle be revisited once redevelopment is complete to assess whether a TPT could be accommodated in its renewed form, architectural plans and concept drawings indicate that this is unlikely. Laakhaven therefore serves as a clear illustration of how evolving urban landscapes (particularly those driven by housing demand) can foreclose opportunities for waterborne logistics. While the redevelopment of former industrial waterfronts is both understandable and often desirable, it also risks creating a logistical blind spot that potentially increases road-based freight movements through dense urban areas for flows that were historically served by inland

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waterways. This increased congestion subsequently increase the external costs associated with the transport. The issue is thus not redevelopment per se, but the need for closer alignment between urban planning decisions and their longer-term implications for urban freight distribution, congestion, and associated external costs. Thus, for the purposes of this report, Laakhaven exemplifies this tendency in the redevelopment of urban sites previously used for waterborne logistics.

5.3.4.2. DEN HAAG / DELFT AREA 2: THE BINCKHORST DISTRICT

The second industrial area of Den Haag regards the *Binckhorst* district. Here, an array of industrial sites (red on Figure 5-35) and unused brownfields (yellow on Figure 5-35) necessitate further investigation vis-à-vis a potential TPT application. For the purposes of this analysis, this area has been split into two distinct subareas: the *Binckhortshaven* itself, marked as #1 in Figure 5-35, and the *Haagse Trekvilet* part of the *Binckhorst* area marked as #2 in Figure 5-35. Do note that a noticeable rail terminal lies in the northern end of the *Binckhorst* district (pink in Figure 5-35), indicating that the potential transport customers in this area may already be utilising transport modes associated with modal shift: namely, rail. While this does not exclude their interest in IWT or the potential of TPT applications within the district, it may suggest that the modal shift objectives may already be somewhat met within this area. However, IWT could be seen as a natural partner to rail transport, especially under the strategic umbrella of creating more resilient supply chains in Europe. Thus, IWT in the Binckhorst district could function as a possible bypass to potential disturbances on the rail network (and, potentially, although less likely, vice versa).

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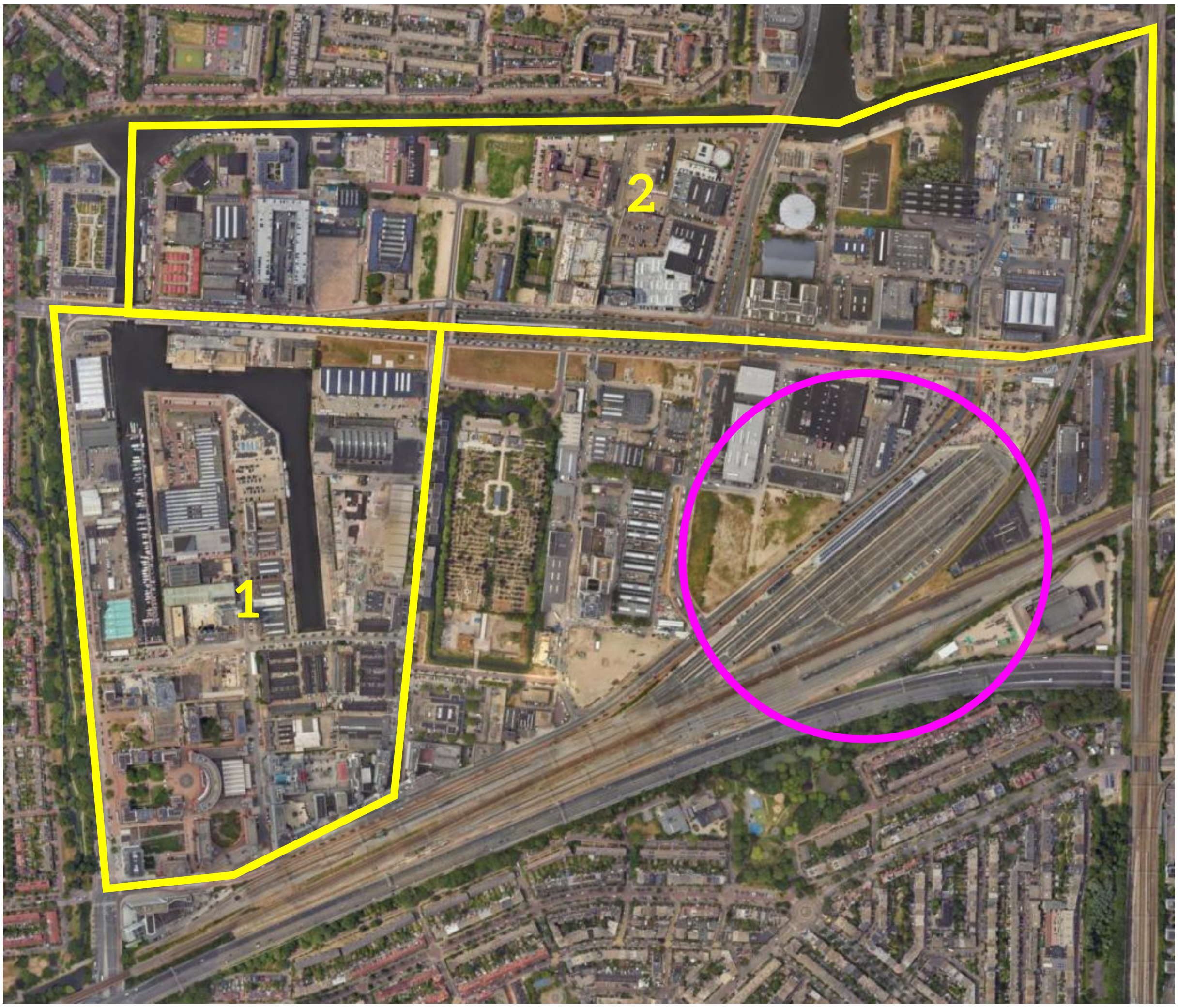

Figure 5-35 Industrial sites in the Binckhorst district
Maps data: © Google | © 2024 Airbus

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Figure 5-36: Binckhorsthaven
Maps data: © Google | © 2024 Airbus

Starting inside the *Binckhorsthaven*, see Figure 5-36, we find a few potential TPT sites. In the southwestern area of the basin (indicated in red on Figure 5-36), there is active transhipment activities already ongoing from a cement contractor, *Dyckerhoff Basal* (red #1 on Figure 5-36, and in more detail to the right in Figure 5-37). As has become a repeating setup throughout the TPT analysis, then the cement contractor uses most of the waterfront for compartmentalised storage units to store dry bulk cargoes related to cement production. On the quay itself, a rail-mounted-gantry crane is operating in a somewhat inaccessible manner given that the storage units are blocking off immediate access to the crane – similar to other cement terminals within this analysis. This could be an interesting TPT-related setup to ensure that the crane is not tinkered with whenever the location is not in full operation. Furthermore, while the crane is located onshore, when looking at the aerial view of the terminal in Figure 5-37, one can visualise the fixed pier upon which the crane is operating as a floating barge instead. In this way, the onshore terminal would have been merely the storage units and the access points, while the transhipment operations of the terminal would be entirely on a floating platform. This indicates, once again, that terminal operations could be partly or fully undertaken from floating platforms. This setup could also free up space shoreside that would originally be used for transhipment equipment, thus greatly reducing the surface area needs for the TPT concept.

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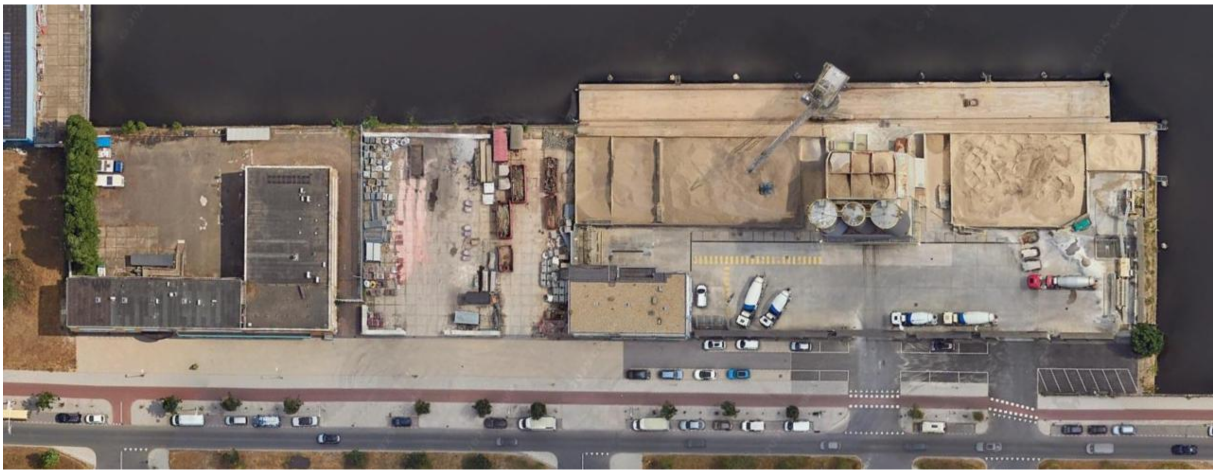

Figure 5-37: Southwestern area of the Binckhorsthaven basin (red #1, #2, and #3 of Figure 5-36)
Maps data: © 2024 Google

Next to the cement contractor is a storage plot of some sorts, without any indication as to ownership (red #2 on Figure 5-36, and in more detail in the middle of Figure 5-37). This has been observed previously, e. g., in Leiden. This site could potentially be used for TPT transhipment purposes, if reorganised, or for TPT storage purposes. The quay itself measures around 40 m. in length, which would allow for a smaller inland vessel, e. g., the AUTOFLEX CEMT II, to be moored alongside. The overall plot area is around 1.500 m^2. Furthermore, the perimeter is fenced off, and access is controlled via a manually operated gate.

The last location (red #3 on Figure 5-36, and in more detail to the left in Figure 5-37) host the Information Centre of *Binckhorst*: a public building where various information and participation meetings are held between citizens and businesses. However, it seems the establishment is "temporarily closed" in an indefinite period. From a TPT perspective, this location seems highly relevant when combined with the neighbouring storage plot. The quay length is a little above 50 m., and the perimeter is fenced. The overall plot size is around 1.000 m^2, of which around 125 m^2 is available for transhipment operations and 700 m^2 for storage. The remaining area is for entry and exit. The plot also has a building which is used temporarily, and which could potentially accommodate personnel, whether permanently or temporarily, that needs to be present for the TPT operations to take place. While access is secured with fencing and a gate, access from the main road to the transhipment area is given by a somewhat narrow road; potentially too narrow to allow for larger trucks to pass through, but wide enough to allow for vans etc.

Moving clockwise around the harbour basin, the next waterfront area can be found in the northwest (the upper part of Figure 5-36, and in more detail to the left in Figure 5-38). Starting with the green #1 marking on Figure 5-36, one finds a decent-sized location of *Bouwmaat XL*, a building materials supplier, which could be an interesting location for a TPT application. The plot is constituted of approximately 3.500 m^2 of parking space next to the main building, approximately 1.250 m^2 of outdoor storage area toward the harbour basin of which around 700 m^2 can be considered the waterfront/quay area. The entire area is fenced off, with an option also to fence off the storage area from the parking lot (markings on the ground indicate that this may have been the case previously). The quay is around 70 m. in length and around 10 m. width for the potential transshipment area (making up the ca. 700 m^2 of quay area for transshipment purposes). This location could be relevant both for *Bouwmaat XL* themselves to receive materials over the water and for them to potentially create additional revenue by

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allowing their premises to be used for transshipment purposes outside opening hours – or even inside opening hours should there be an appropriate access control procedure established between the parking area and the storage area. Right next to the location is a noticeably-sized brownfield, which could potentially be developed to increase the storage capacity of the site (or any other TPT location within the Binckhorsthaven).

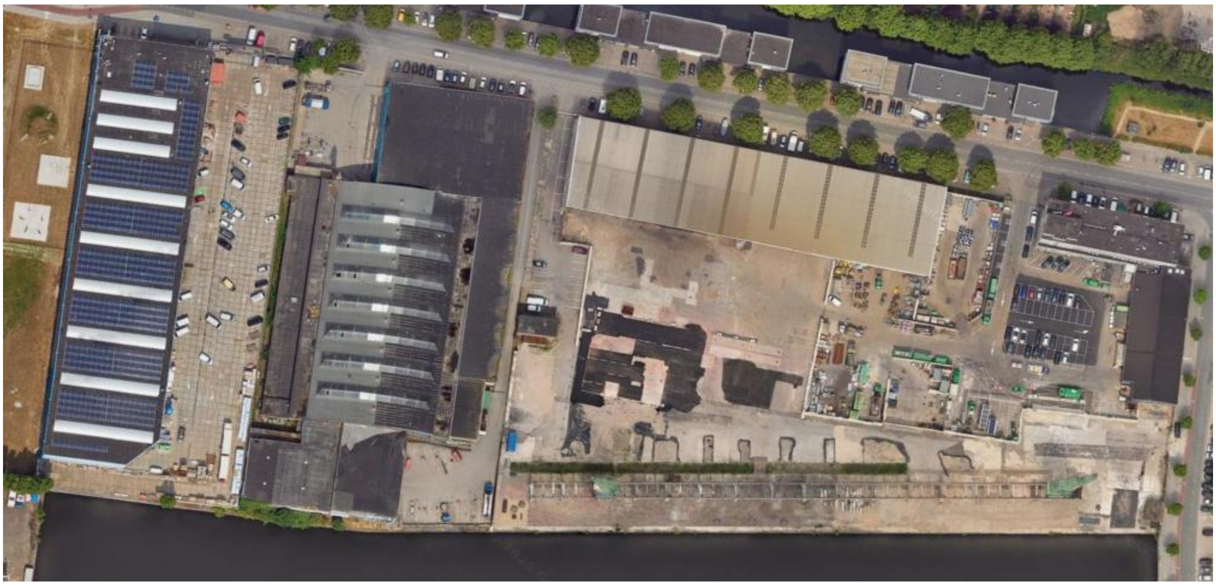

Figure 5-38 *Binckhorsthaven northern basin*
Maps data: © 2024 Google

Continuing clockwise in Figure 5-36, the next plot belongs to a waste management service company, *Renewi* (green #2 on Figure 5-36 and in more detail in the middle of Figure 5-38). While a less opportune site when compared to the *Bouwmaat XL*, the *Renewi* site may also allow for a TPT application if storage can be done elsewhere. The quay is around 30 m. in length, making it able to just accommodate the AUTOFLEX CEMT II vessel, and the transhipment area another 30 m. in depth, allowing for a total operational area of around 90 m2. While this may be enough to operate a reach stacker and offload a few containers, it will likely not be enough space to accommodate prolonged storage if cargo operations are relatively frequent. Consequently, the *Renewi* site is best combined with additional storage facilities elsewhere within its vicinity. However, the site could still be relevant for TPTs, with Renewi themselves potentially interested in importing waste and exporting recycled products.

The last site on the northern waterfront on the northern basin of *Binckhorsthaven* is a large road construction company, *BAM* (green #3 on Figure 5-36 and in more detail to the right in Figure 5-38). In fact, the site is a good micro-illustration of the idea behind the TPT concept because in order to understand the site, one must examine it in a historical perspective. In 2020 (Figure 5-39, left), the site was actively used for the transshipment of various dry bulk cargo with two large rail-mounted gantry cranes running on a rail system above the bulk storage units located on the quayside. The entire area was active as a dry cargo production and transshipment site. From satellite imagery, it appears that different types of bulk cargoes have been transhipped at this location. In 2025 (Figure 5-39, right), the terminal seems to be almost entirely abandoned. The large dry bulk storage units on the quayside have been removed, and approximately half of the site has been converted into a parking lot and 50-75 percent of the large, grey steel hall (top left of the figures) has been converted into an area with padel courts (open from 0800-2300). The remaining 25 to 50 percent of the steel hall

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remains empty (based on drone footage embedded In the background of the padel sites website here). While a dry bulk company is still present in the shape of the road construction company, *BAM*, the entire area near the waterfront has been seceded (in addition to the aforementioned parking lot for the padel courts). From a news article found here, it appears that the discontinuation of the dry bulk terminal has been a decision made by the municipality of Den Haag, in agreement with BAM, in order to redevelop the site into a residential area with at least 400 homes. Consequently, time will tell if this remains a relevant TPT location, or if it will be redeveloped in such a manner that little to no waterfront area will remain for potential transshipment purposes.

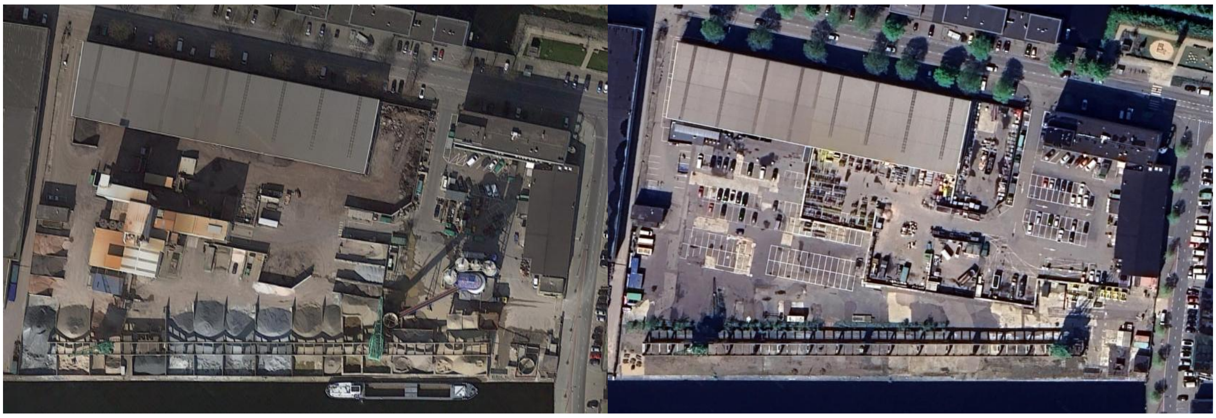

Figure 5-39 Historical development of the BAM terminal
Maps data: © 2021 Google (left) | © 2025 Airbus (right)

In the middle of the Binckhorsthaven is a "central pier" (marked in yellow on Figure 5-36), which is used for various bars, creative spaces and offices. These locations are all poorly applicable to a TPT solution given their immediate use of the quay space. A larger parking space exists with a gate controlling access to/from the area. The water-facing part of this parking lot could perhaps be repurposed into a TPT concept. The quay of the parking area, seemingly in a good condition with a hard waterfront, is around 60 m in length with the overall parking area around 3.800 m2. This should be ample space for both transhipment operations and storage capacities. At closer inspection, it appears that the parking space and its access control is intended to service the *Titaan*, the *Caballero Fabriek* and the *Loetje* – a co-working space, a creative centum and a restaurant (see Figure 5-40 non-shaded zone). All access to this area goes through the parking lot gate (see Google Street View image here). While the *Titaan* and *Caballero Fabriek* are open from 0800 to 1800 and 1600 respectively (both closed on Saturdays and Sundays), the *Loetje* restaurant is open from 1130-2200 throughout the week. Were it not for this restaurant, the area could be entirely closed off after 1800 and allow for transshipment in night hours from 1800-0800 or in the weekends whenever the area is completely closed off. While there are currently no residential zones in the area, which would make potential noise pollution from transshipment at night irrelevant, the development of the 400 homes at the former cement terminal site may limit container-based transshipment activities at the site during night. However, if activities could be well-aligned with the operation of the *Loetje* restaurant, the three entities could potentially collaborate on a TPT application, potentially with some of the startups inhabiting the co-office spaces, in a way that provides an additional revenue stream for the three entities.

At the very end of the pier (Figure 5-40, left side), another parking space is available, which also could be used for TPT activities. However, in order to align the modus operandi of the three entities making up this area, one could designate this parking area to the activities of

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the three entities and leave the larger parking area to TPT activities – primarily storage of cargo. Also, while there is currently no fencing that prevents restaurant guests from entering the TPT zone, a fence could be erected (e. g., between the "red" road and the "grey" parking) to make the separation of activities clearer – should a fence be necessary at all. If parking is still needed for the *Titaan* and *Caballero Fabriek* during day hours, the TPT could be operationalized so that it is only in function from 1800-0800 on weekdays and throughout the weekends – or so that the grey parking area is used "dynamically" with a "fluent" border between the need for parking for *Titaan* and *Caballero Fabriek* and the need for storage for the TPT concept.

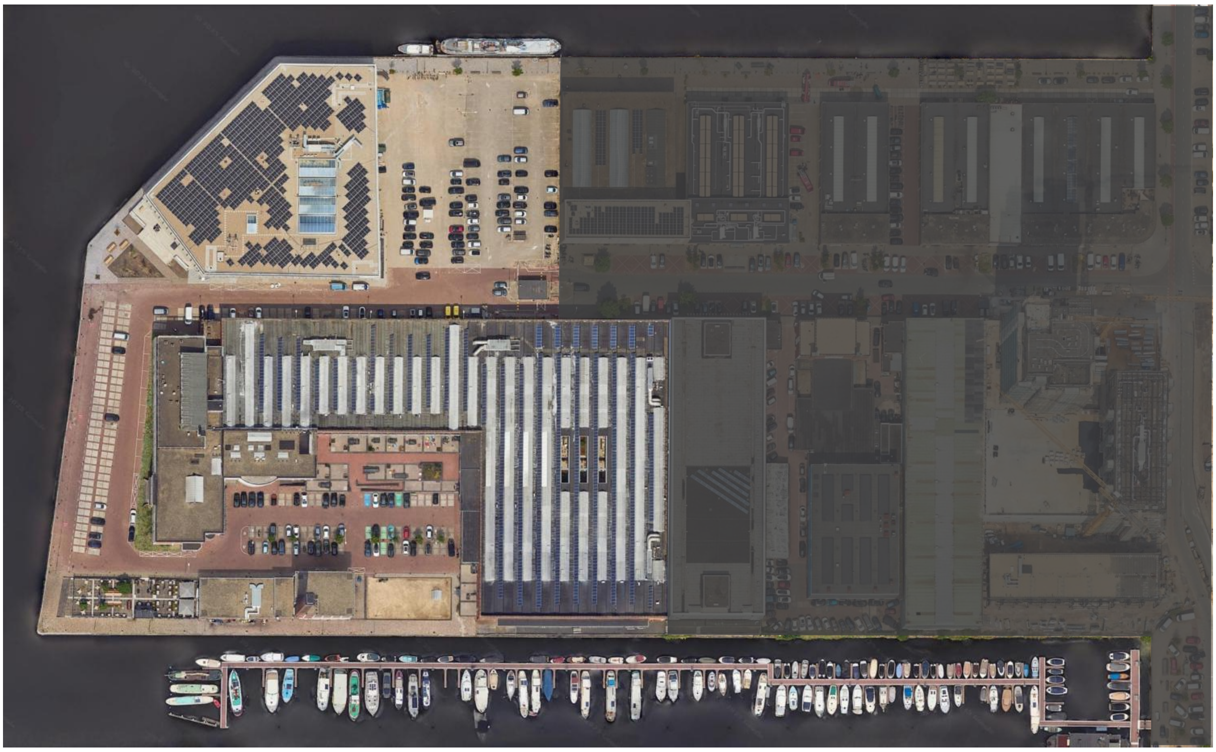

Figure 5-40 Binckhorsthaven central pier
Maps data: © 2023 Google

The rest of the southern basin in the *Binckhorsthaven* (marked in blue on Figure 5-36) does not have any sites immediately relevant to TPT applications given narrow waterfront space and the presence of a long boat pier with leisure crafts that extends into the basin and makes manoeuvring within it very difficult.

On the *Haagse Trekvilet* part of the *Binckhorst* district, i.e. "outside" of the Binckhorsthaven, one finds another few potential TPT locations (see Figure 5-41). For the purposes of this study, this area is divided into two by merit of the Trekvliet Bridge.

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Figure 5-41: *Haagse Trekvilet* part of the *Binckhorst* area
Maps data: © 2023 Google

In the southern area (leftwards in Figure 5-41), there are a few waterfront entities such as an apartment complex, restaurants and a small shipyard for leisure crafts. None of these locations appear relevant due to limited quay space (both in the length of the quay and the necessary operational area for transhipment activities) and poor accessibility for large road vehicles. However, one site in particular stands out for its TPT potential.

Figure 5-42: Brownfield area in *Haagse Trekvilet* part of the *Binckhorst* area

An apparently former water-related site, now an abandoned brownfield, can be found with its own small harbour basin dividing the site into two areas, see Figure 5-42: a smaller paved area measuring ca. 3.000 m2, and a larger brownfield area measuring ca. 7.500 m2. The basin is around 80 m long and 10 m wide, making it perfectly capable of hosting CEMT II vessels. While the site needs to be cleared, its potential as a TPT site is obvious. For instance, transhipment could take place simultaneously from each side of the basin, potentially making transhipments really fast. However, the brownfield temporarily known as LABgrond, is currently in the process of being set up as a plot of land for various events, such as an outdoor classroom, a city beach, a concert location and a harvest festival etc. While this is a potential restriction to the TPT application developed for the site, it also posits an opportunity: leisure-focused amenities, such as festivals and concerts, are time-based events that require a potentially significant amount of items transport to and from the site. An event-based TPT could be erected on a more sporadic basis to aid the *LABgrond* site in achieving these things in a more sustainable, waterborne manner. Currently, only the paved 3.000 m^2 area is fenced off, which would allow it to operate almost entirely independently for the events taking place at the site without heavy cargo handling equipment interacting or interfering with the public.

In the northern area (rightwards in Figure 5-41), next to the Trekvliet Bridge, is what appears to be a bike depot with a 70 m long quay and an 800 m^2 potential transshipment space, see Figure 5-43. The bike depot is built around a fixed infrastructure that does not seem easily removable, meaning that the site will have restricted surface area for storage. However, when

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zooming out, one finds a storage area to the north (right) of the transshipment site. Infrastructurally, this site does however not appear immediately opportune for transshipment activities due to its overgrowth near the water and generally somewhat awkward waterfront shape (i.e. few "straight" quays) – at least compared to the southern (left) quay. Thus, the two locations could potentially be combined into a TPT concept where transhipment happens at one location and storage happens at another location. This would probably require cargo handling equipment both for taking cargo on/off the ship (e. g., a reach stacker) and for moving cargo to/from the transhipment area and the storage area (e. g., a terminal tractor). It may however also be that this could be undertaken sequentially by one.

Figure 5-43 Bike depot and storage area next to the Trekvliet Bridge
Maps data: © Google | © 2025 Airbus

From an on-ground perspective, see Google Street View image here, it appears that both areas are fenced off, with a small area in-between with public access. This means that access can be controlled for the areas individually, i.e. the transshipment and the storage area. This could potentially allow for creative set-up regarding equipment needs and cargo handling (e. g., one type of equipment, such as a reach stacker, only for the transshipment area and storage area, with another type of vehicle, e. g., a terminal tractor to operate between the two areas). The road access to the site is convenient and is a stone's throw away from a rail terminal with which the site could potentially be integrated.

Third, in the norther most part of the area shown in Figure 5-41, a massive waste management centre, *NV HMS*, can be found, see Figure 5-44. This site seems very well positioned to deploy a TPT solution immediately into the NV HMS own operation with regards to waste management – especially considering that many of the waste containers on the site appears to be containerized, potentially refurbished shipping containers. The site could of course also offer services to other industrial actors in the area.

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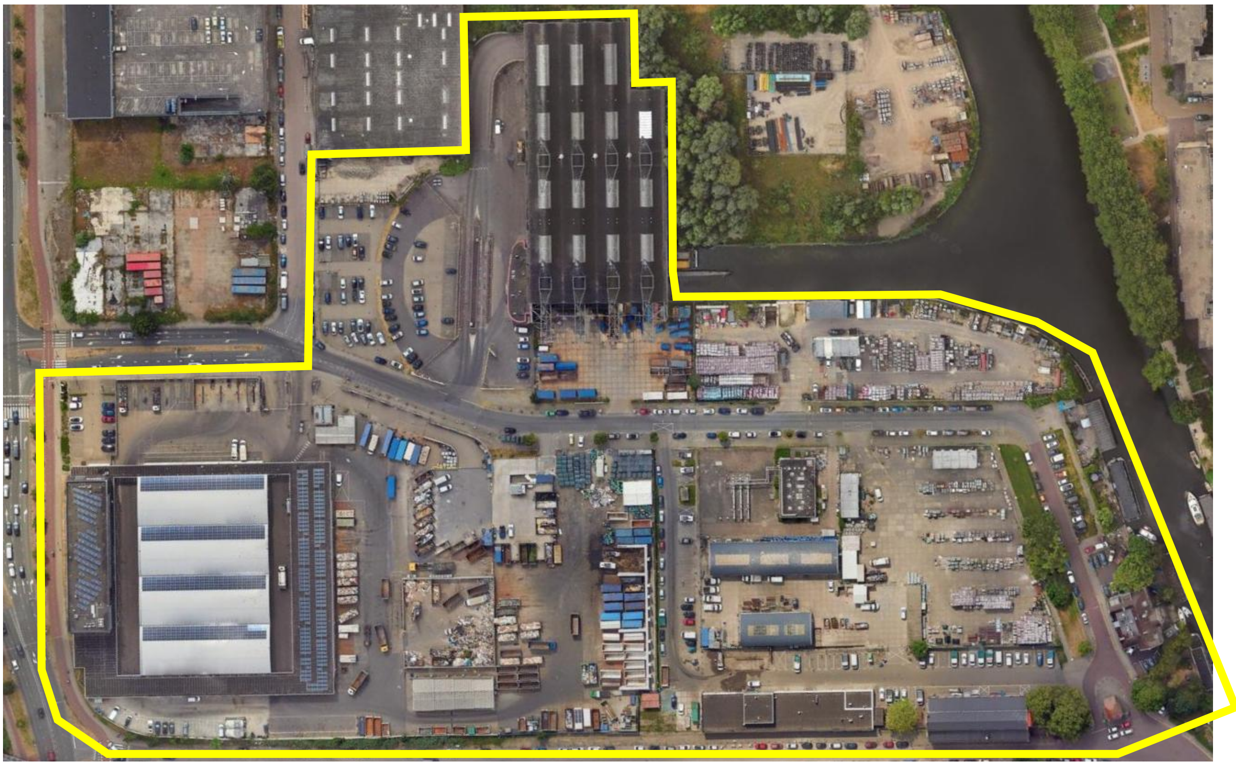

Figure 5-44: Waste management centre, *NV HMS*
Maps data: © Google | © 2023 Airbus

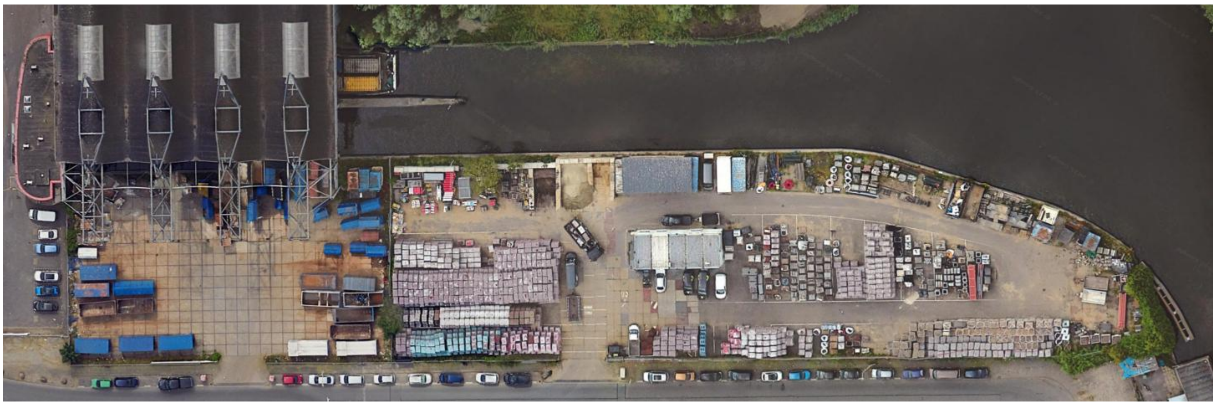

Figure 5-45 NV HMS waterfront interface
Maps data: © 2023 Google

Looking at the waterfront interface itself, see Figure 5-45, one finds 140 m of quay, with the innermost part (left) constituting an uninterrupted length of around 80 m (after which the quay bends). It appears that this waterfront is already used for transhipping waste to/from inland ships with what seems to be some type of rail-mounted gantry (RMG) crane, see Google Street View image here, where containers appear to be transferred from a vessel, and here. Consequently, it appears that the site is already accustomed to using waterborne transport in its operations. It would be worth investigating further if this RMG crane could be used for the transshipment of local commercial goods and cargoes – either to/from the Binckhorst industrial area specifically or Den Haag generally. This could potentially be scaled up through a modular TPT concept that can easily adapt to changes in transport demand without severely increasing financial risks (such as additional transshipment equipment).

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As a last but crucial comment on the Binckhorst District regards the redevelopment plans issued by the city of Den Haag. Seen through the lens of the Binckhorst, the TPT is not a nostalgic and romanticised holdover of abandoned ports but a stress test of what we really mean by "green transition." Along the Trekvliet, the municipality is preparing a phased Waterfront Park stretching across roughly 220.000 m^2 of newly public waterfront – a development framed explicitly as climate adaptation and expected to begin construction of its first sections in 2028/2029. For a district whose urban metabolism was historically waterborne, and where the Binckhorst's inner harbours once functioned as working quays, erasing the last practicable points of water access risks trading measurable logistics decarbonisation for picturesque climate mitigation. Inland waterway freight consistently outperforms road on energy use and lifecycle emissions per tonne-kilometre, precisely the kind of low-impact backbone dense cities claim to want. If the Waterfront Park truly aims to future-proof Den Haag, then the most climate-literate move may be to reserve, design and permit at least one reversible, low-noise TPT along the Trekvliet during the park's long, phased roll-out. In doing so, inland vessels will be allowed to berth and discreet transhipment to take place into a "Waterfront Park and Port" rather than paving over that option altogether. Otherwise, when the lawns are laid and the bollards gone, Den Haag may discover that in the name of climate adaptation it has landscaped away one of its few genuinely low-carbon freight alternatives – and with it, a pragmatic path to a cleaner, decongested city.

5.3.4.3. DEN HAAG / DELFT AREA 3: THE WESTVLIETWEG INDUSTRIAL ESTATE

In area 3, on the *Rijn-Schiekanaal* in the *Leidschenveen-Ypenburg* district of Den Haag, one finds the Westvlietweg Industrial Estate – a 45 ha "business park" in the Vlietzone district strategically located near Den Haag's city center and key arterial roads. It hosts approximately 335 companies and accommodates a diverse range of businesses, including technology, logistics, retail, waste management etc[2]. However, when looking at the site more in detail, it seems that any TPT concept deployed at this site would be exceptionally challenging vis-à-vis its transhipment operations. That is, not only is there a public road running next to the waterfront which, as has been mentioned for previous sites with similar architecture, is challenging from a public-private coordination perspective around safety. While this is not an absolute barrier, it is an important operational parameter that should be included in the design requirements of the TPT components. Furthermore, between the public road and the waterways, a bicycle lane and a pavements/side walk that are currently used by citizens (see Google Street View image here). This constitutes an increased coordination issue on top of the public road and is a difficult challenge that must be overcome if a TPT concept should successfully be deployed here. In addition, various parts of the waterfront are overgrown with various greenery, which also would have to be removed (and, again, the integrity of the underlying infrastructure to be inspected) in case a TPT concept should be deployed there. Overall, this means that while it is not an impossibility to develop and implement a TPT at this site, such concept would need to overcome the aforementioned challenges of operational intersections with public roads, bicycle lanes and pedestrian paths – both from a safety, security and societal perspective (e. g., social acceptance etc.)

[2] https://westvlietweg.nl/

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Figure 5-46 The Westvlietweg Industrial Estate
Maps data: © 2023 Google

5.3.4.4. DEN HAAG / DELFT AREA 4: HAVEN VAN RIJKSWIJK

In area 4, one finds the *Haven van Rijkswijk* (see Figure 5-47). The zone is home to the European Patent Office (EPO), the research institute TNO, and various smaller enterprises, some of which may potentially be interested in waterborne transport services. East of the location (right, in Figure 5-47) is a larger DHL distribution centre which, potentially, could also be interested in collaborating with a TPT location within the Rijkswijk industrial zone.

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Figure 5-47: Haven van Rijkswijk industrial zone
Maps data: © 2016 Google | © 2023 Google

Looking at the waterfront area of the Rijkwijk industrial zone, on finds several businesses with water access. After closer inspection, two areas stick out which needs more granular inspection vis-à-vis a potential TPT application: a brownfield (yellow in Figure 5-48), an unidentified storage area, presumed to be belonging to the larger governmental building of *Rijkswijk* (red in Figure 5-48) and a longer pier with various entities (green in Figure 5-48).

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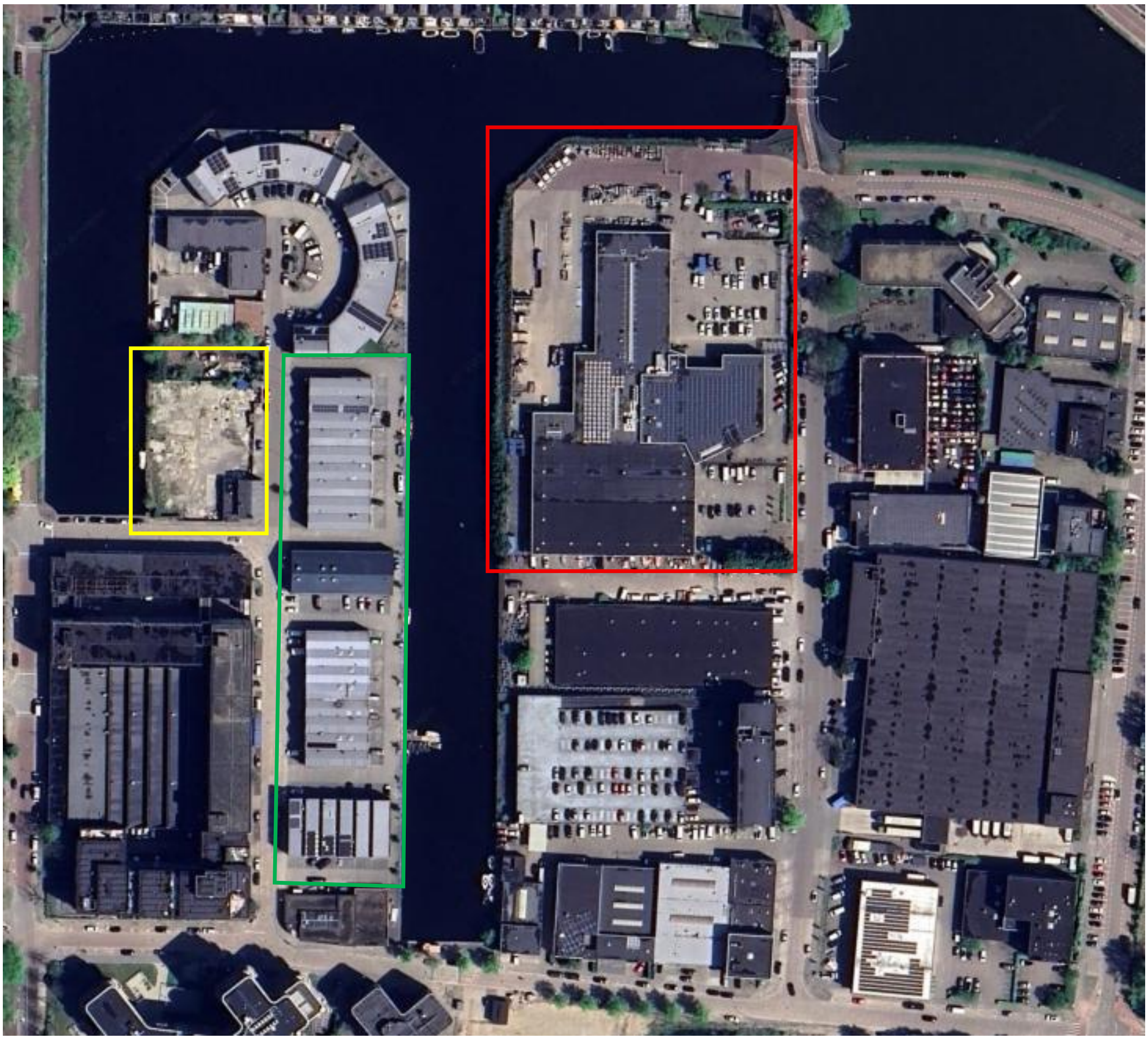

Figure 5-48 Zoomed in view of the *Haven van Rijkswijk*
Maps data: © Google | © 2024 Airbus

Starting with the governmental building (red in Figure 5-48 and to the right in Figure 5-49), the site has a lot of overgrowth along what appears to be an otherwise decently maintained quayside of 80 m (130 m if counting the entire quay length). However, significant clearing work would be needed to take down the rather large pine trees located along the waterfront. On the northern, shorter, quayside, two quays of around 30 m in length each are also available, both with significantly less overgrowth. However, given the AUTOFLEX vessel's length of 55 m, these quays are far from optimal, which means that focus should be placed on the longer, 80 m quay. The area is fenced, meaning access can be controlled and the security and the safety of the site can be guaranteed, which may be an important TPT requirement from an ISPS perspective – however, it may not be entirely necessary as seen from the analysis of other locations within this chapter. While it is difficult to determine exactly what the water-facing area is used for, except an obvious inference that it seems to be used for some kind of storage potentially related to some of the activities undertaken by this department of the *Rijkswijk*, the location could potentially be used for TPT purposes if the *Rijkswijk*'s governmental stature does not impede initiating such activities. Regardless, given that the location is used on a classical 0900-1700 basis, with Saturday and Sunday closed, there is ample grounds to intuit that the location could be used outside opening hours – as long as

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potential noise or light pollution does not significantly disturb the residential neighbours north of the premise (see Figure 5-48 and/or Figure 5-52). While this is not an impossibility, it may prove a somewhat difficult challenge. All of this is still, however, dependent on the overgrowth on the waterfront being removed in some shape or form.

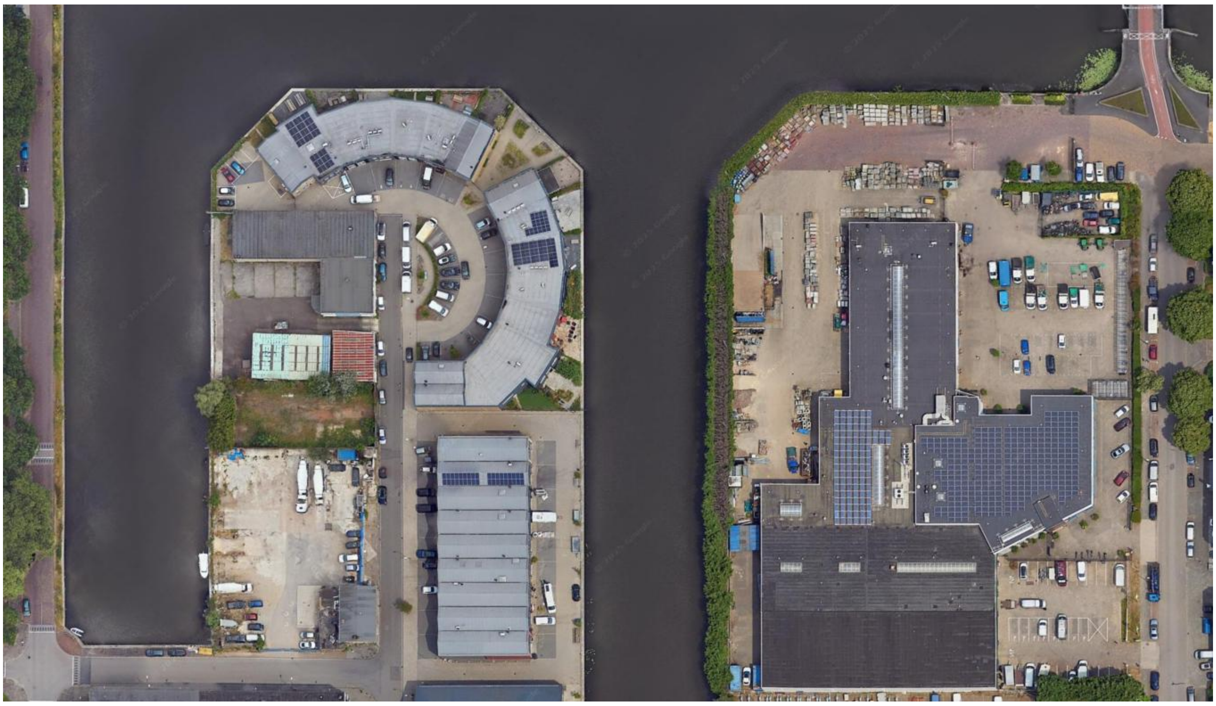

Figure 5-49 Rijkswijk's governmental building (right) and the brownfield (left) in *Haven van Rijkswijk*
Maps data: © Google | © 2024 Airbus

With regards to the brownfield (yellow in Figure 5-48 and to the left in Figure 5-49), another picture emerges. While not an outright brownfield, given that the location seems to be used for parking of various vehicles etc., it comes across as a relatively undeveloped site. Based on satellite imagery, the site seems to have been used as a cement transhipment site (-2017), then abandoned (2017-2020), then as a second-hand car dealership (2020-2022) and since 2022 it appears to have been (re)abandoned to some extent. The quay is around 50 m long, with the overall plot area constituting 2.000 m^2. While this may be just short of the 55 m of the AUTOFLEX CEMT II vessel, it should still be possible given that the effective cargo area onboard is not the full length of the vessel. This should give ample space for both transhipment and some storage. From historical images, one can observe that the brownfield has previously been used as a bulk terminal up until around 2015, see Figure 5-50 and the Google Street View image here. Consequently, one can assume that the terminal could relatively easily be redeveloped into a container terminal. Fencing and a gate is already present, implying that access restriction can be ensured.

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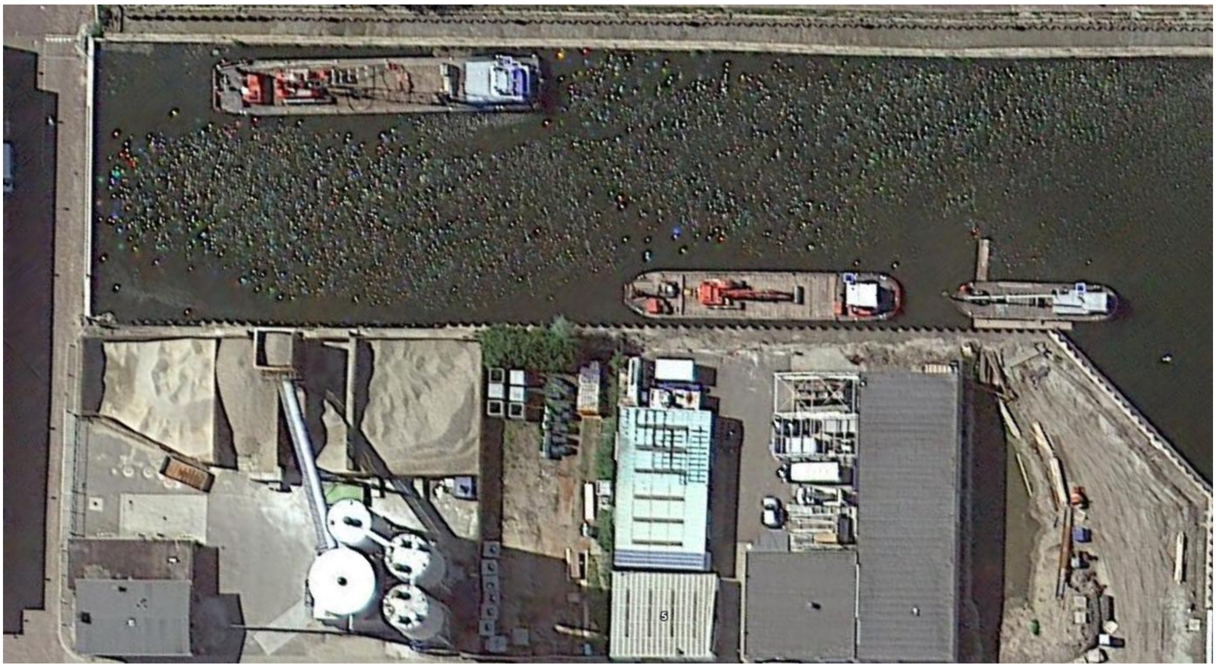

Figure 5-50 Historical image of the brownfield in *Haven van Rijkswijk (Den Haag)*
Maps data: © 2013 Google

The last site that requires more granular investigation is a waterfront consisting of four relatively recently erected buildings (active in their current form as of 2018 according to historical satellite images). The site and its buildings are marked in green in Figure 5-48 and can be seen in detail in Figure 5-51. Interestingly, the buildings are erected in individual modules resembling classic Dutch architecture, with, apparently, each module inhabited by an individual company (see Google Street View here for images of these buildings and modules). This means that a multitude of various companies inhabit this site, some of which may, potentially, be interested in smarter transport services such as those provided by the AUTOFLEX system.

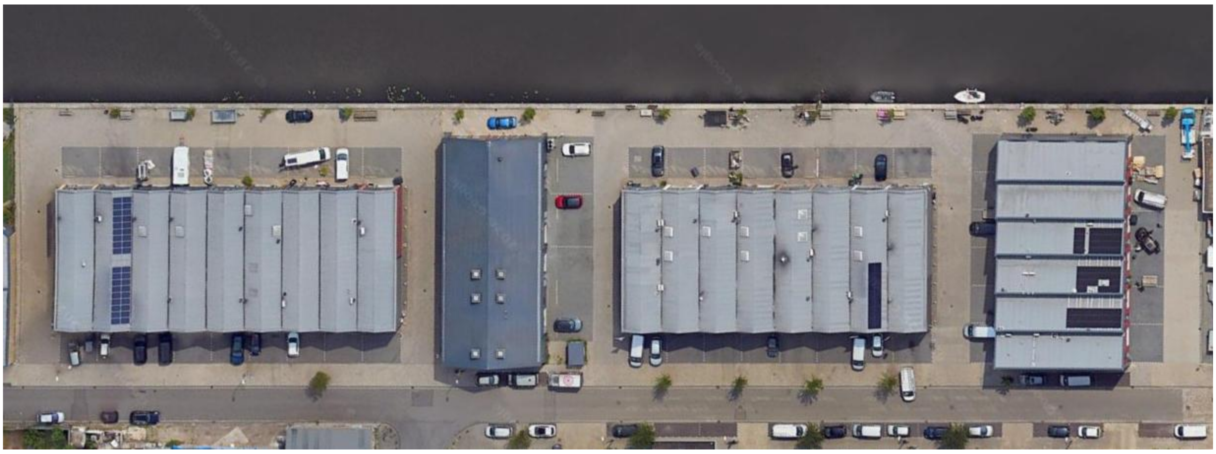

Figure 5-51 The third potential TPT site in *Haven van Rijkswijk*
Maps data: © 2013 Google

The total length of the quay across site is 190 m, with a width of 5 m on the narrowest parts (i.e. the quay area near the second and fourth building, counting from the left on Figure 5-51) and of ca. 13 m on the widest parts (i.e. the quay area near the first and third building, counting from the left on Figure 5-51). Consequently, a TPT solution at this location would probably prefer to be established on the wider parts of the waterfront, as this would provide enough

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space for transhipment operations. However, should a floating transhipment solution be developed, as mentioned earlier, the narrower parts of this site could potentially also be used. As can be seen from Figure 5-51, the first and third buildings, where the waterfront space is wider, are used as access points for cars and vans belonging to the various businesses in the buildings. Consequently, if a TPT solution should be established here, it would need to be carefully aligned with the existing businesses and their access needs. Opposite the site of the Rijkswijk governmental building, this area is by no means fenced, which means that all of the premise is freely accessible both in day and night hours. Consequently, while the space could be used at night when the business can be assumed not to be active, it would be rather difficult to ensure that the sites are fully accessible for transhipment services during night. However, with a floating transhipment platform, one could potentially visualise a solution where transhipment is taking place even in day hours, with containers placed along the quay in the "grey" area and then emptied and filled directly by the businesses that reside in the buildings. Whenever a given container is sufficiently filled and/or emptied, it would be returned into the AUTOFLEX transport system. This would be interesting for part-load logistics solutions.

In addition to the terminal areas themselves, an adjacent storage area could potentially be cooperated into a hybrid TPT concept with remote storage facilities to accommodate either/both additional cargo volumes or/and cargo that needs prolonged storage periods (as can be seen in the top right corner of Figure 5-52). If first- and/or last-mile transports are ordered to drop off cargo at this adjacent storage site, TPT-related transport vehicles, such as a terminal tractor or a truck, could transport the units from the storage site to the transhipment site (and vice versa). This potentially avoids clogging the access points around the transhipment area if multiple third-party trucks arrive simultaneously and allows for asynchronous operations in the terminal-ship and the terminal-hinterland interfaces. Similarly, a larger adjacent brownfield could be redeveloped into a buffer/elasticity storage zone for the TPT specifically, and for road borne cargo distribution in general. From a larger perspective, this terminal-storage area decoupling could potentially also be deployed for the adjacent DHL distribution centre (the larger red area to the right in Figure 5-47), creating a DHL-tailored TPT concept in the Rijkwijk industrial zone.

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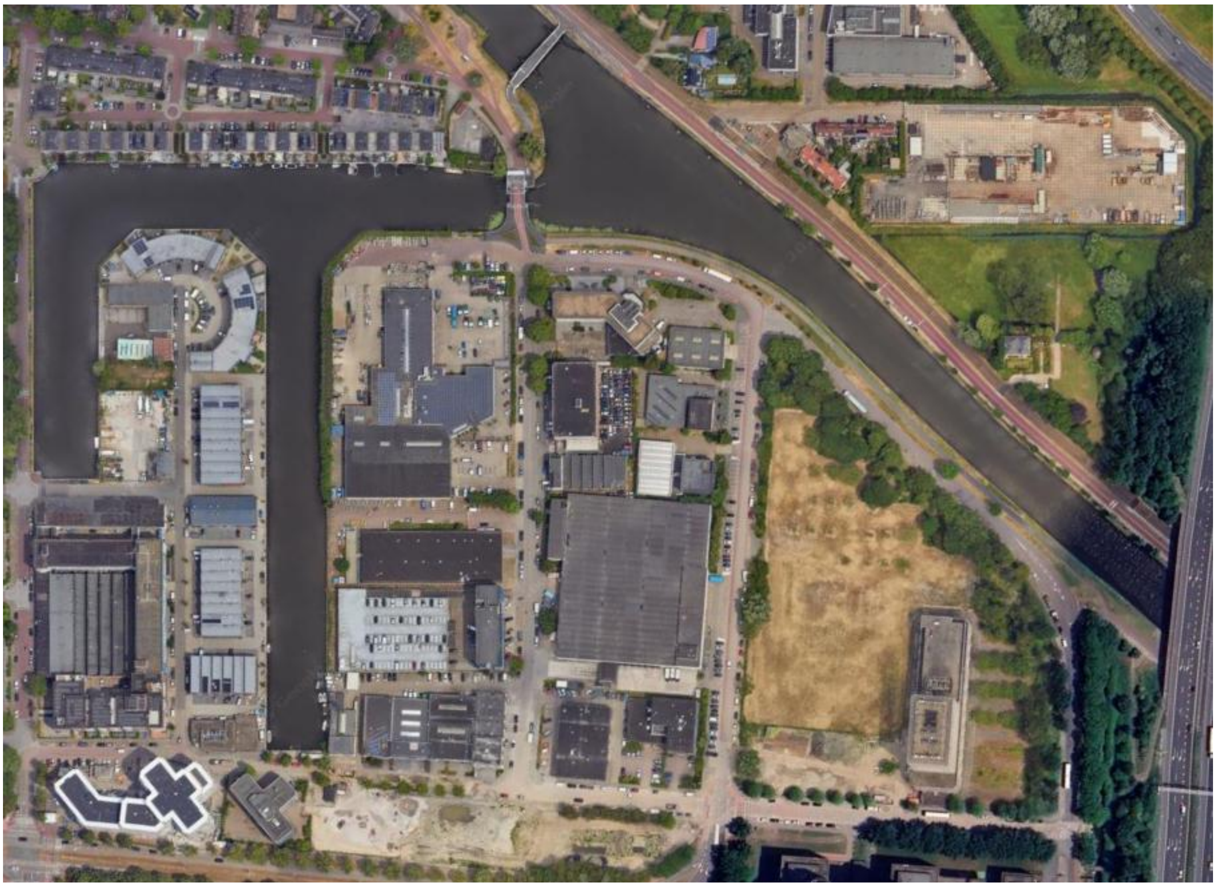

Figure 5-52 Potential storage area (top, right) in the vicinity of Haven van Rijkswijk
Maps data: © 2016 Google | © 2023 Google

5.3.4.5. DEN HAAG / DELFT AREA 5: GIST- EN SPIRITUSFABRIEK TE DELFT

Moving on to the fourth area of Den Haag / Delft, one finds an appendix to the Rijn-Schiekanaal called "Gist- en Spiritusfabriek te Delft" (literally translating to "Yeast and spirit factory of Delft"). The area is home to the enormous *DSM-Firmenich* biotech and chemical plant (having iteratively developed from its original use as a Yeast and Spirit plant). That is, while other businesses do exist in the industrial area, including, for instance, a garden centre, car dealerships etc., the most dominant presence by far is the *DSM-Firmenich* complex and its associated *Biotech Campus*, where more than 1200 people collaborate across startups, researchers and *DSM-Firmerich* (see Figure 5-53). Also, on the other side of the canal, a logistics distribution centre, *Van der Lee (Vervaeke Group)*, exist, which does not have a waterfront access, but which could potentially be interested in moving some of their freight transport over a waterborne modality. Consequently, any TPT application in this area would predominantly be tailored to the needs of *DSM-Firmenich.*

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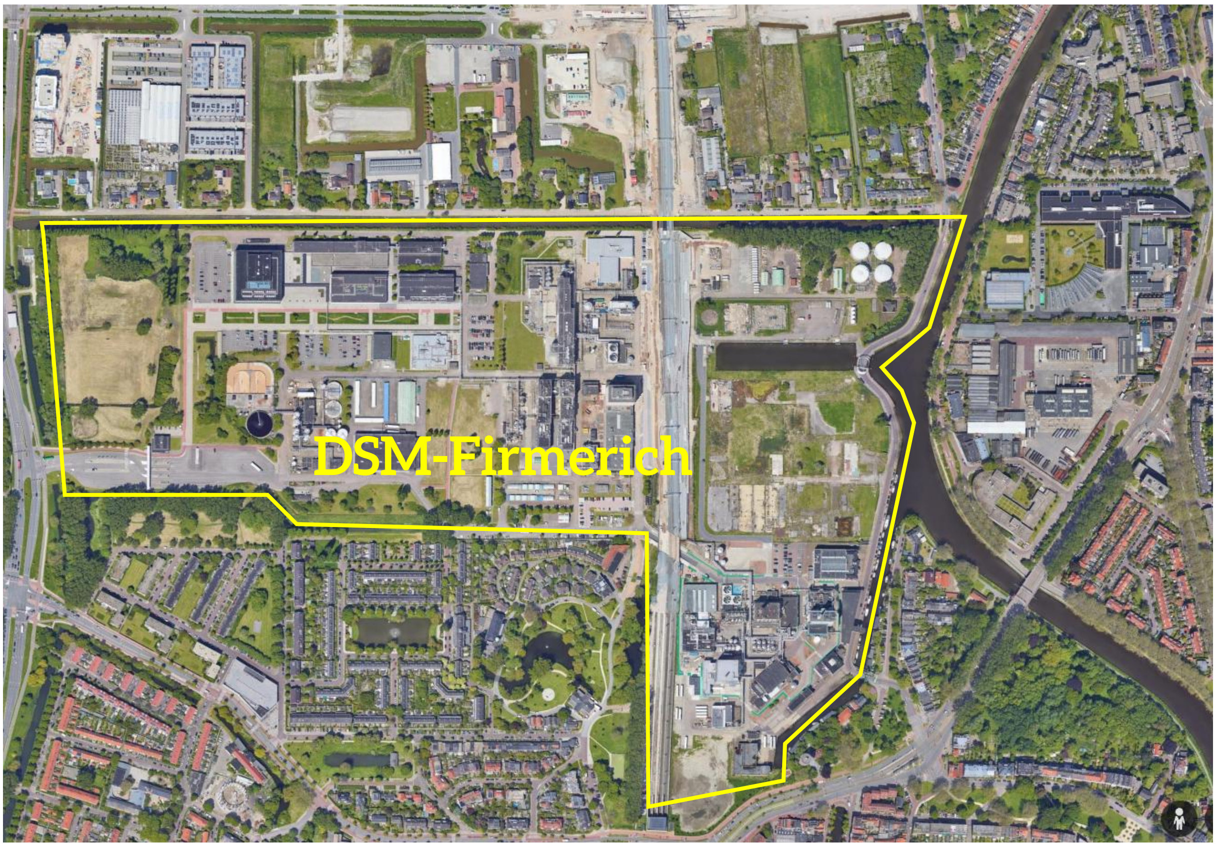

Figure 5-53 The industrial area of Gist- en Spiritusfabriek te Delft (the DSM-Firmerich plant, including its Biotech Campus, is highlighted in yellow)
Maps data: © 2021 Google

Looking at the waterfront interface itself, it appears that a liquid bulk terminal is already active, presumingly delivering various chemicals to/from the *DSM-Firmenich* plant (left in Figure 5-54). The available quay area is ca. 60 m length (i.e. perfect for the AUTOFLEX vessel) and could potentially be used whenever the terminal is not used by tanker vessels. The transhipment area would constitute around 3.000 m^2, with two additional quaysides, paved storage areas of around 1.000 m^2 each and another storage area of around 5.000-6.000 m^2. Furthermore, the terminal seem integrated directly to rail transport options too (bottom left of Figure 5-54), which could potentially be seen as a reason for *not* implementing a TPT application here given that there is already a modal shift enabled via the rail transport system. Regardless, IWT services could still be relevant to the *DSM-Firmenich* plant and its many startups on the *Biotech Campus*, and the already existing terminal could conveniently enable this. It is, however, important to note that *DSM-Firmenich* is not a logistics company, but a chemical company, and thus it is not farfetched to think that they might only be interested in enabling transshipment of their own and the Biotech Campus' commodities (and not a modal shift for third parties via their premises). As chemical plants are normally safety critical and commercially sensitive areas, access may be extremely restrictive for irrelevant third parties – but this in turn also makes it possible to ship potentially dangerous and/or sensitive cargoes to/from this location.

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Figure 5-54 Overview of the Gist- en Spiritusfabriek te Delft harbour basins
Maps data: © 2022 Google

A large brownfield can also be spotted on Figure 5-54 – however, this is still within the *DSM-Firmerich* premises and is thus not an "available" brownfield as such. Furthermore, as seen on Figure 5-54, it appears that construction work is ongoing in turning this brownfield into a developed area. This can be confirmed by a news piece from Omroep Delft found here, where the brownfield is seen with various buildings and general infrastructural developments at around 1:13 minutes into the video. However, there is still available space to further develop the area into a cargo terminal and/or distribution centre for container- and trailer-based cargoes. It is however difficult to access if this is within the interest of DSM-Firmenich, and given its ongoing expansion efforts to keep up with its growth (as mentioned in the news piece from Omroep Delft), it is not unthinkable that the remaining brownfield area will be developed for other purposes than cargo handling and logistics operations.

Consequently, a TPT could be deployed at the "Gist- en Spiritusfabriek te Delft" location, but one would assume that this TPT would primarily, if not exclusively, serve potential container transports to/from the large chemical plant *DSM-Firmerich* and/or any of the startups or researchers in its *Biotech Campus*. In addition, the TPT here could be connected with rail transports, increasing transport resilience by having two modalities to divert transports through, as well as for *DSM-Firmerich* (and the *Biotech* Campus) themselves to optimise their supply chains through multimodal transport use.

5.3.4.6. DEN HAAG / DELFT AREA 6: DELFTSE SCHIE

Lastly, on the Delftse Schie, the fifth area of interest in Den Haag / Delft can be found. The area can roughly be divided into two zones, divided by a major highway (i.e. a northern and a southern part), see Figure 5-55. In addition, the *Bedrijvenpark Ruyven* (subarea #3 on Figure 5-55) is located in near vicinity to these two zones – an area which host various entities such as a large *Albert Heijn* distribution centre, a medical supplies distribution centre and various logistics firms. While the area is not immediately next to the waterway, a highway conveniently runs between the industrial area(s) on the waterway and the *Bedrijvenpark*

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Ruyven. This means that actors within the *Bedrijvenpark Ruyven* could be considered either transport customers in themselves or potential additional storage opportunities.

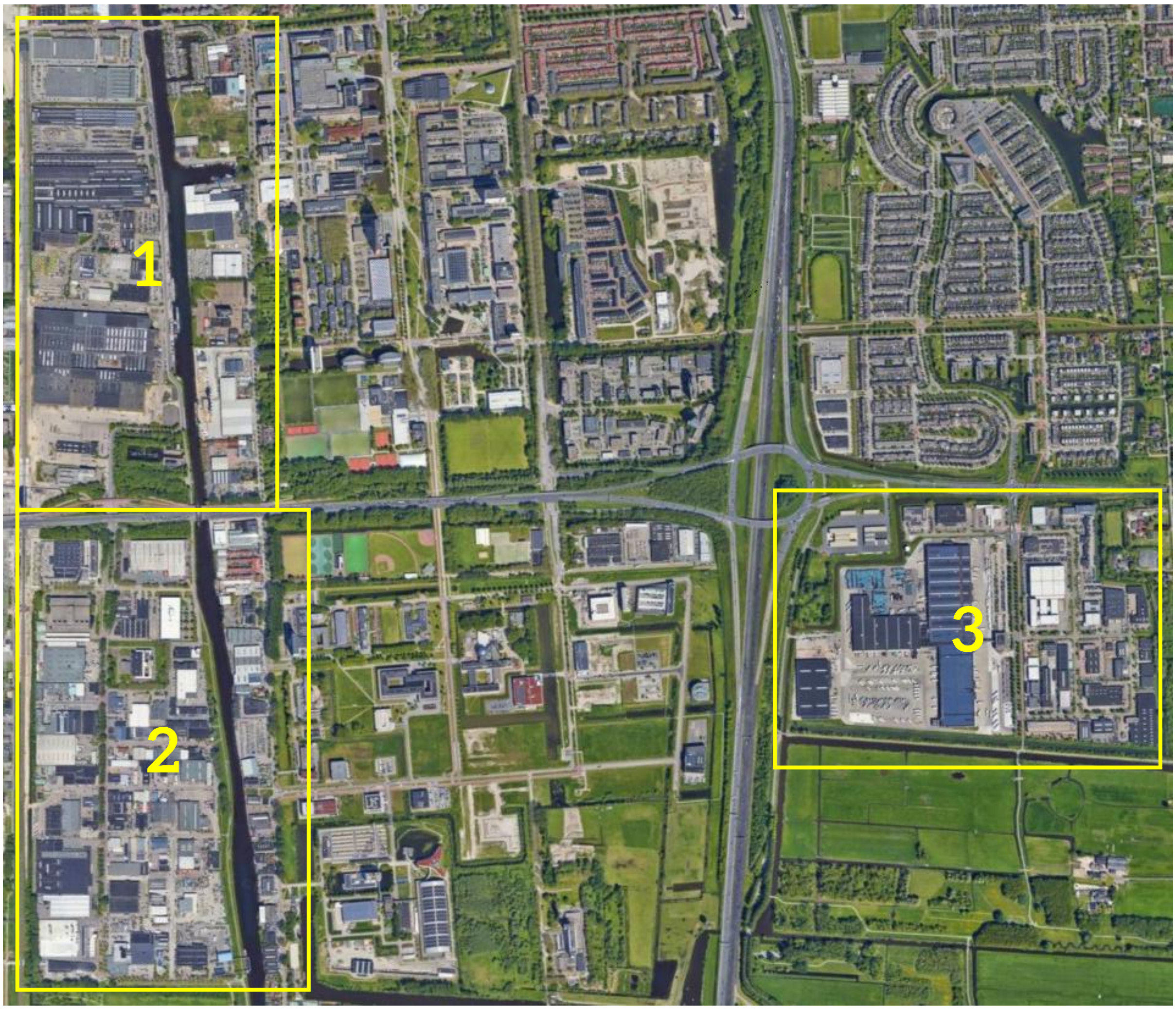

Figure 5-55: Industrial areas on the Delftse Schie
Maps data: © 2021 Google

Starting with the northern most subarea (subarea #1 on Figure 5-55), there seems to be a western (lower) and an eastern (upper) waterfront (see Figure 5-56).

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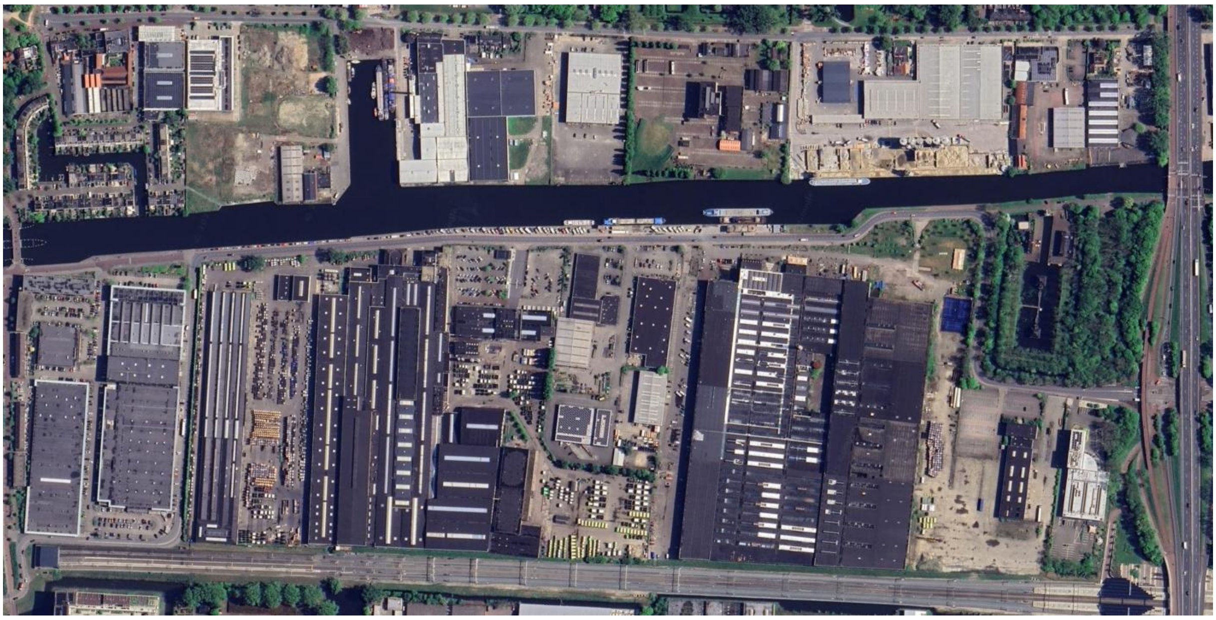

Figure 5-56 Subarea #1 on the Delftse Schie
Maps data: © Google | © 2025 Airbus

From satellite imagery, the western waterfront can be seen already accommodating inland vessels. Actually, this specific location can inform the TPT development tremendously given the below satellite image taken from 2019 (see Figure 5-57). While this occurrence can be observed on satellite images throughout many years, including 2025, the 2019 image tells the story the best. On the left of Figure 5-57, we see an inland vessel of around 58 m long, seemingly a general cargo ship carrying dry bulk cargo of some sort. Quayside is what appears to be a standard digger which is emptying (or filling) the cargo of inland vessel unto (or from) trucks on the side on the quay. Once loaded or emptied, depending on the operation, the trucks can drive off on the public road. The quay itself, which is where the trucks are parked on, is merely 9 m wide. Consequently, the operational area of this "terminal" is the 58 m (length of inland ship) by the 9 m of the quay space. However, this indicates that the transshipment area of TPTs does not require a lot of space. If we briefly assume that a standard ISO container is around 4 m. wide, this means that two rows of containers could be placed on this particular quayside. If the containers can be stacked 2-3 upon each other, and with two rows of stacking, this small quayside could potentially accommodate 2x2x2 – 8 x 40 ft containers – more than half of the AUTOFLEX Oscar II vessel's size. It thus appears that TPTs could be remarkably small, if the operation is otherwise fluent and accommodated by the site. From a streetside photo, it seems that this digger is relatively permanently located at the site (see Google Street View here). Furthermore, it appears that little to no access restrictions are required for this bulk TPT operations.

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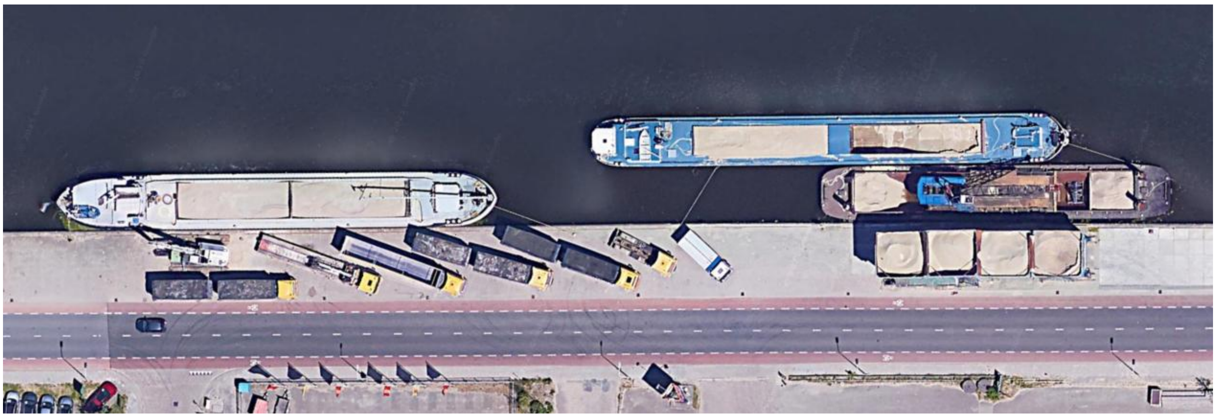

Figure 5-57 Satellite image of transhipment operations on the Delftse Schie (2019)
Maps data: © 2019 Google

Next to this, another informative observation can be made from Figure 5-57. Quayside, a four-compartment bulk storage unit is placed as a storage infrastructure to accommodate incoming dry bulk cargoes. Moored to the quay is a craned inland vessel, which does not seem to have any *transport* aim but instead purely a *transshipment aim*. Said differently, the barge is semi-permanently moored to the quay. On the outside of the craned vessel, a larger cargo vessel of ca. 63 m can be seen to/from which the crane loads/unloads (given the landside operations, it seems more likely to be unloaded than loaded, but this will be explained in depth later). This indicates that the entire *transshipment* component of a TPT could potentially be afloat – i.e. not on the landside of the terminal itself. This changes things somewhat remarkably, because it adds a modular and flexible component to transshipment practices without necessitating larger areas, landside or operational space nor operational commitment from landside entities. Said differently, there is no need to "store" any equipment ashore. This enables concepts where vessel loading/unloading operations and cargo drop-off/pick-up operations can be undertaken in a completely asynchronous manner. It is not far-fetched to believe that the two mobile diggers as seen at this site could have been diggers permanently fixed – either on the quay (vis-à-vis the left case) or on a floating platform (vis-à-vis the right case).

From drone footage in Google Street View here, it can be concluded that the transhipment platform/component itself does not have any apparent propulsion mechanism onboard, relaying entirely on a push boat to transport it. This is interesting also because it a) decreases the necessary CAPEX and maintenance required of the platform, and b) potentially address issues with regards to tampering with transhipment equipment (e. g., as a consequence of vandalism or intended theft). Furthermore, the blue storage infrastructure appears to be elevated above ground; a design feature that allows trucks to pass underneath the structure with an empty trailer and be filled up with cargo (as can be seen on Google Street view here). This appears both a remarkably simple yet ingenious way to expand the terminal "vertically" and eradicate the need for an additional transhipment from terminal to truck (as would be necessary in terminals where cargo is stored at ground level). Further work should potentially look into how a similar structure could be design for the offloading of containers unto quayside areas with modest space, as well as how containers could potentially be loaded back into the structure in some manner. It could be that containers could be stored in systems akin to multistorey car parks, although at a much smaller scale, which would allow containers to be stored vertically while still being accessible independently whenever they need to be moved further along the transport chain. Consequently, while this location is not intuitively deemed appropriate for a TPT concept, the existing transhipment operations show how innovative TPT concepts could be compiled.

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From a storage perspective, the quayside locations do not offer a lot of possibilities. However, when combined with the nearby industrial actors, as seen in Figure 5-58, including *Prysmian* (red), a world leader in energy and telecom cable systems, a truck transport company (pink), a container provider (green), various home suppliers and furniture stores (yellow) and an event/museum/creative centre in the former NKF cable factory (blue). While *Prysmian* is an obvious potential transport customer with its high production volumes of cables (on cable drums), so too could be the various home suppliers and furniture stores. Perhaps subparts of the cable factory could be repurposed into storage sections for the TPT, while the truck transport company also could aid in making storage space available for the TPT concept.

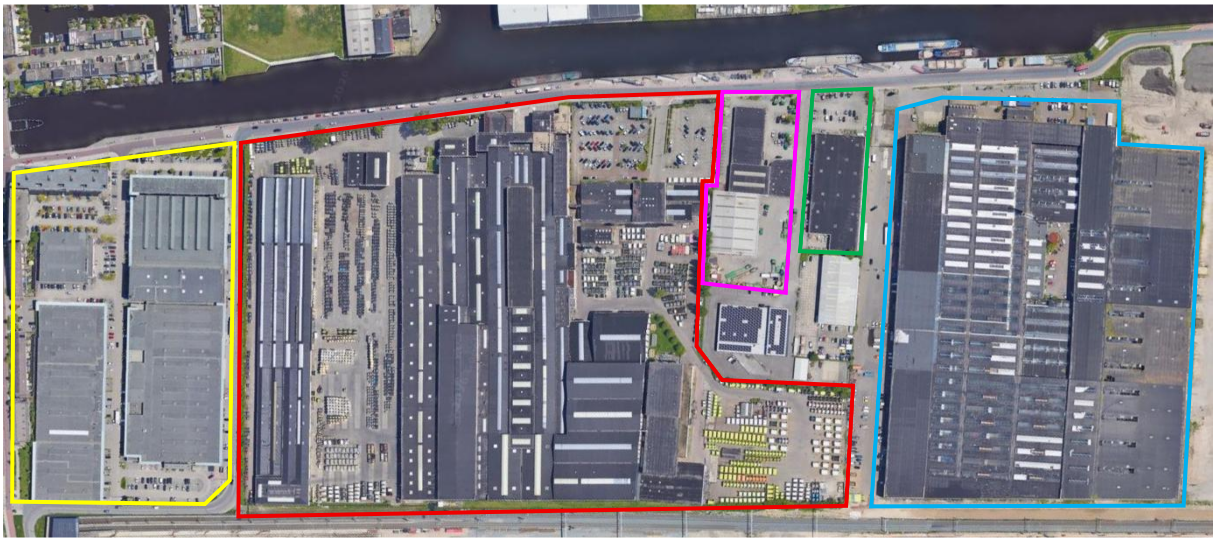

Figure 5-58 Actors in subarea #1 on the Delftse Schie
Maps data: © 2019 Google

On the other side of the canal, another potential TPT area can be spotted. First, in the northern most part, an interesting brownfield area can be found, which appears to be owned by *Octatube:* a civil engineering company. While the plot is mostly covered in gras, it exhibits hard quay walls both against the canal itself – an area that seems currently to be used by the neighboring residential area for swimming in the canal – and within the adjacent small basin. On the other side of the basin is *Hordijk EPS:* a company producing packaging and insulation products. As can be seen on satellite imagery (see Figure 5-59), the basing is already hosting various inland vessels, however none of these seems to be engaged with transshipment activities at the site. The basin is around 125 m long and 50 m wide, potentially enabling multiple AUTOFLEX CEMT II vessel simultaneously, or the ingenious use of floating platforms for transshipment purposes (as seen across the canal). The *Hordijk EPS* site does not seem well suited to deploying a TPT concept given that its main access point to the latter parts of the building is provided via a road next to the basin and thus cargo handling in this area, in opening hours, may create unwanted bottlenecks. However, there may be a way to use this area at night instead, hence avoiding simultaneous use of the space. However, on the site of the brownfield, a paved area of ca. 2.000 m2 can be found along the basin, providing amply opportunity for transshipments on the site. Furthermore, the remaining area of the brownfield, i.e. the *field* itself, could be further developed to ensure storage capacity and elasticity at the site.

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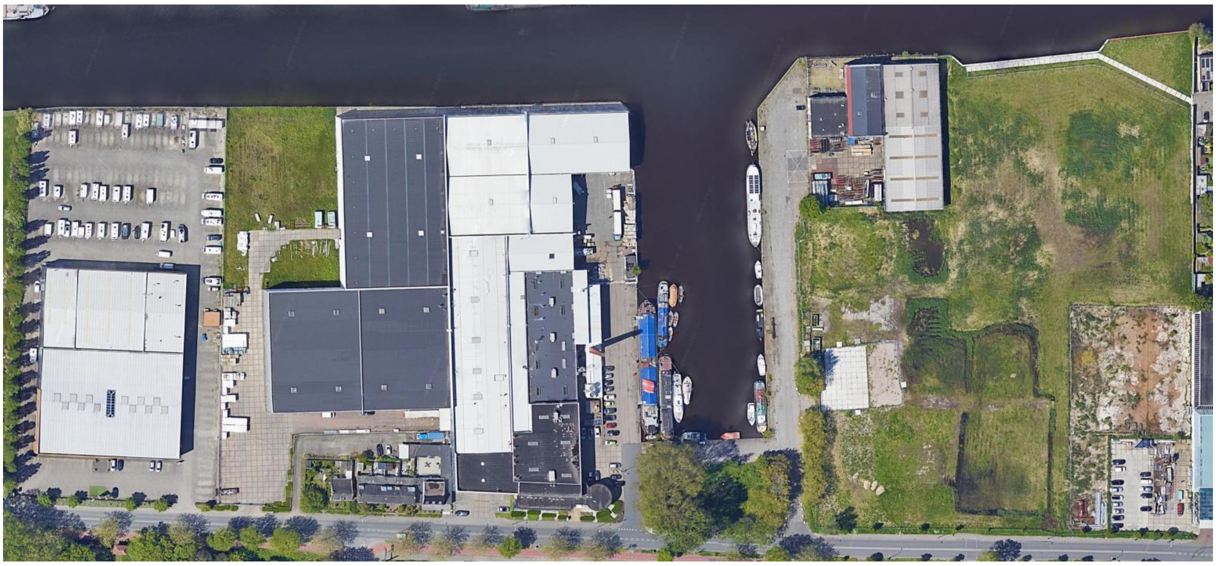

Figure 5-59 The Tree Composites, Hordijk EPS and Octatube (brownfield) premises
Maps data: © 2021 Google

Moving further southwards (i.e. left on Figure 5-59), we find another area: a parking lot of another civil engineering company, *Tree Composites*. Today, the site is primarily inhabited by caravans, but the hard quayside, ca. 75 m in length, could provide ample opportunity for a TPT concept. The entire parking lot itself, not counting the building etc., is around 4.500 m2, which should be more than enough space to offer both transhipment and storage services. However, due to the nature of *Tree Composites*, they may not be interested in opening a transhipment terminal within their premises given that they are primarily involved with delivering construction *consultancy services* and not construction *materials*. However, third parties could potentially lease the space and themselves orchestrate the development, management and maintenance of a TPT concept at this location. That is, TPT solution could potentially be created at sites with opportune (perhaps historical) transhipment infrastructure without the landlord themselves being interested in or involved with the transhipment operations themselves. Instead, the given entity could benefit from revenue sharing and/or from standard rental contracts. The entire area is fenced off with a gate controlling access.

Another site of interest in the area is the terminal operated by BMN – a building materials supplier that has also been identified earlier in Leiden (subarea #1). The BMN site, shown in Figure 5-60, features a quay of approximately 220 m in length that is actively used for the transshipment of building-related bulk materials. In line with the typical configuration of inland bulk terminals observed in this analysis, the quay hosts a series of storage compartments located roughly 5–6 m from the waterfront, with the space in between occupied by two rail-mounted cranes/diggers that move longitudinally along the quay to load and unload inland vessels. In its current configuration, this setup does not immediately lend itself to container transshipment. The cranes would likely require retrofitting with appropriate lifting attachments in order to handler containers, and their reach appears insufficient to place containers beyond the bulk storage compartments into the hinterland area. That said, a relatively small area of approximately 450 m^2 adjacent to the storage compartments (visible to the right of the compartments in Figure 5-60) could potentially function as a limited storage or buffer area for containerised cargo handled from an AUTOFLEX vessel. Although this space is presently used for minor storage purposes, it could likely be cleared with relatively limited effort.

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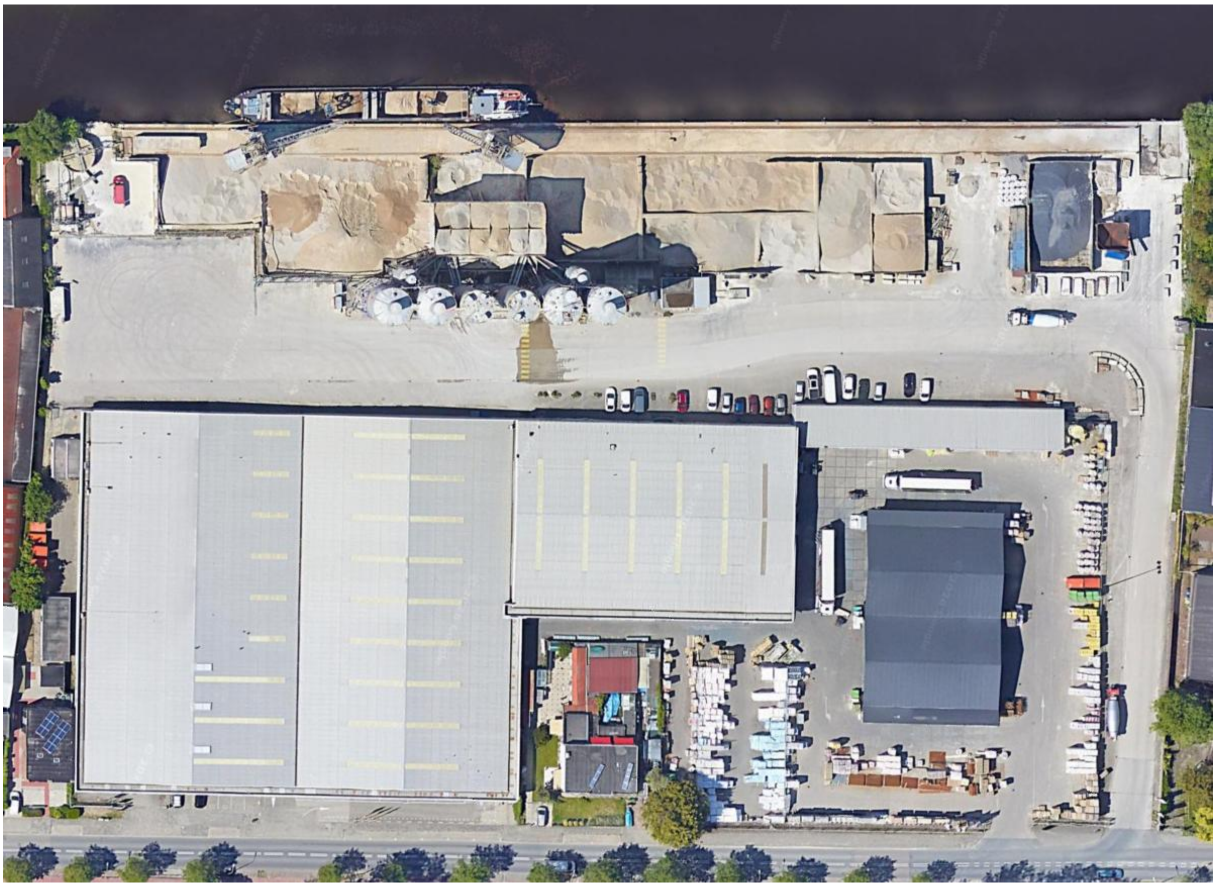

Figure 5-60 The BMN site in Delft
Maps data: © 2021 Google

From a business perspective, it is not self-evident that BMN would be interested in pursuing containerised transport, as the company's core activity is not terminal operations per se but the actual supply of building materials. This is predominantly bulk commodities such as cement and sand, as suggested by the satellite imagery in Figure 5-60. However, observations from inside the BMN store, see their webpages here, indicate a much broader product portfolio, including a wide range of building-related items that are unlikely to be produced on-site. This opens the possibility that BMN could have an interest in transporting smaller volumes of containerised or palletised goods via inland waterways. The site is fully fenced, enabling controlled access and allowing for temporal segregation of activities (e. g., bulk transshipment during weekday daytime hours and potential container handling during evenings or weekends). The apparent presence of forklifts further supports the feasibility of handling palletised cargo and rapidly stripping containers on-site. Moreover, BMN's multiple sites identified in this analysis, including those in Delft and Leiden, could in principle be linked through an AUTOFLEX service, enabling inter-site transports such as balancing of equipment and materials. Finally, the site benefits from convenient road access and a functional separation between the store, warehouse, and terminal entrances, reducing the likelihood of interactions between customers and terminal operations and thereby mitigating safety and security concerns.

The remaining actors on this waterfront constitutes a culture/event venue, a building materials supplier already engaged with the transhipment of dry bulk cargoes with no available space along the waterfront to operate other cargo equipment and/or vehicles, a kitchen furniture store and a rowing club – all of which are deemed not to be suitable for a container-based TPT solution (see Figure 5-60).

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In the southern part of the industrial area, a couple of sites should be mentioned. However, before doing so, it must be noted that the entire waterfront on the western side of the canal (lower bank on Figure 5-61) is restricted by greenery and overgrowth along the quayside, combined with the recurring issues regarding public roads directly neighbouring the waterway. On the eastern side of the canal (upper bank on Figure 5-61), a multitude of smaller enterprises can be found, all with direct access to the canal via hard quay infrastructure. However, the far majority of these sites have buildings too close to the water to allow for transshipment activities to take place without architectural amendments to the site.

Figure 5-61 Southern part of the industrial area on the Delftse Schie
Maps data: © 2021 Google

Figure 5-62 Avalex recycling centre (Delft)

One site worth mentioning is in the southernmost end (right on Figure 5-61): the *Avalex* recycling centre which is actively engaged with shipping containers over the waterways. While the issues of public access persist, it seems that *Avalex* has been allowed not only to extend a cargo crane out over the public road, it also has erected a fence on the public road on each side of the crane, restricting access to only relevant people, see Figure 5-62. This prevents potential safety risks such as people walking and/or driving under containers being transshipped etc. From the satellite image, it seems that the site exclusively handles 20” container units, which fits well with the AUTOFLEX 24 TEU CEMT II vessel. It is worth further studying the details of a TPT application here, especially how third party TPT providers could utilize the *Avalex* on a crane-as-a-service basis, perhaps paying *per move* or *per hour* (like how Rolls-Royce introduced *Power-by-the-Hour* concepts in both aviation and maritime). Rearranging the terminal could further allow for potential cargo storage area to

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the left of the crane, combining the transshipment (and subsequent transportation) of both finished and recycling-bound products and materials. Also, a small unidentifiable storage area can be found in the vicinity of the *Avalex* terminal, which may enable asynchronous drop-off/pick-up and transshipment operations, similar to what was identified for the lumber store based TPT in Leiden, as well as other locations.

The other potential TPT site in the southern industrial area is the *KPS Delft* garden centre on the other side of the canal due to its large open storage area, see Figure 5-63. While this area is currently used for the storage of various unidentifiable, assumingly garden-related, items, a hard and somewhat well-maintained quay well of almost 100 m in length indicates that this site could potentially be optimized to include transshipment activities – either for *KPS Delft* themselves and/or other third parties. These third parties could either use the site continuously or in the garden centre's off-hours (i.e. 1700-0700 on weekdays, 1200-0800 on Saturdays and the entire Sunday). Actually, it may be that an entire TPT concept could be set up around using these sites on Sundays (or weekends) in order not to interfere with the daily operations of the sites. That is, for instance, the DFDS barge operating between Ghent and Antwerp is in the DFDS Ghent Terminal twice per week. No other barge operations are currently running to/from the terminal, meaning that the barge-designated area of the terminal is empty up to 5 days per week. This operational schedule could potentially be transferred and adapted to a TPT site where transshipment is only available on Sundays (or weekends). However, the more frequent the route, the more often the TPT is being used, the better its financial return-on-investment (as a rule-of-thumb, at least). Thus, the precise operational schedules of the specific TPT sites would have to be calculated as a function of a broader logistics system. However, it is worth noting that Sunday-only transshipment activities, i.e. when businesses such as the garden centre are closed, are not far-fetched. The challenge then becomes where to store terminal-related equipment (often just a single reach stacker) in this period.

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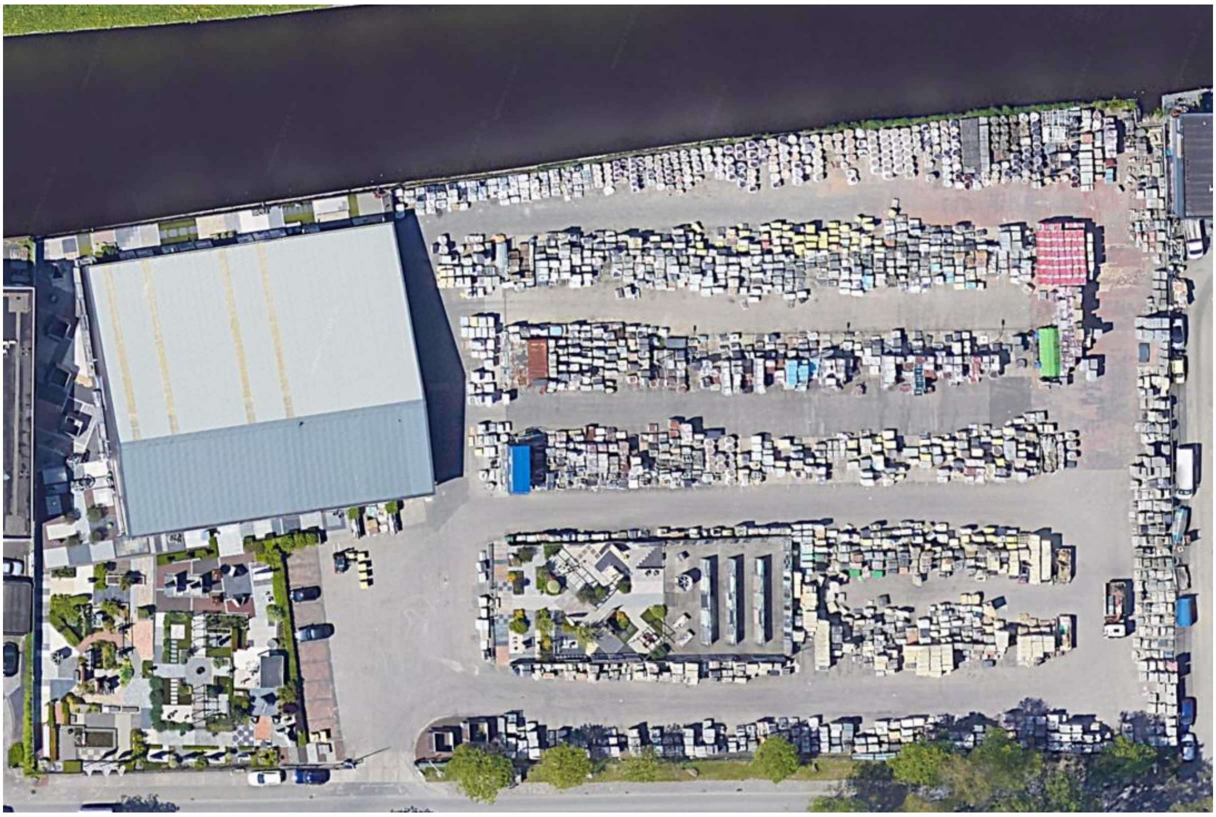

Figure 5-63 KPS Delft Garden Centre
Maps data: © 2021 Google

5.3.5. MSC CLUSTER 5: ROOSENDAAL

In Roosendaal, we find a larger industrial area with connection to a CEMT IV waterway, a rail connection and the highways A17 (going south-north) and A58 (going south-east). At closer inspection, see Figure 5-64, one finds a larger industrial area close to the waterway (area 1) and a smaller industrial area somewhat farther from the waterway to the southeast (area 2).

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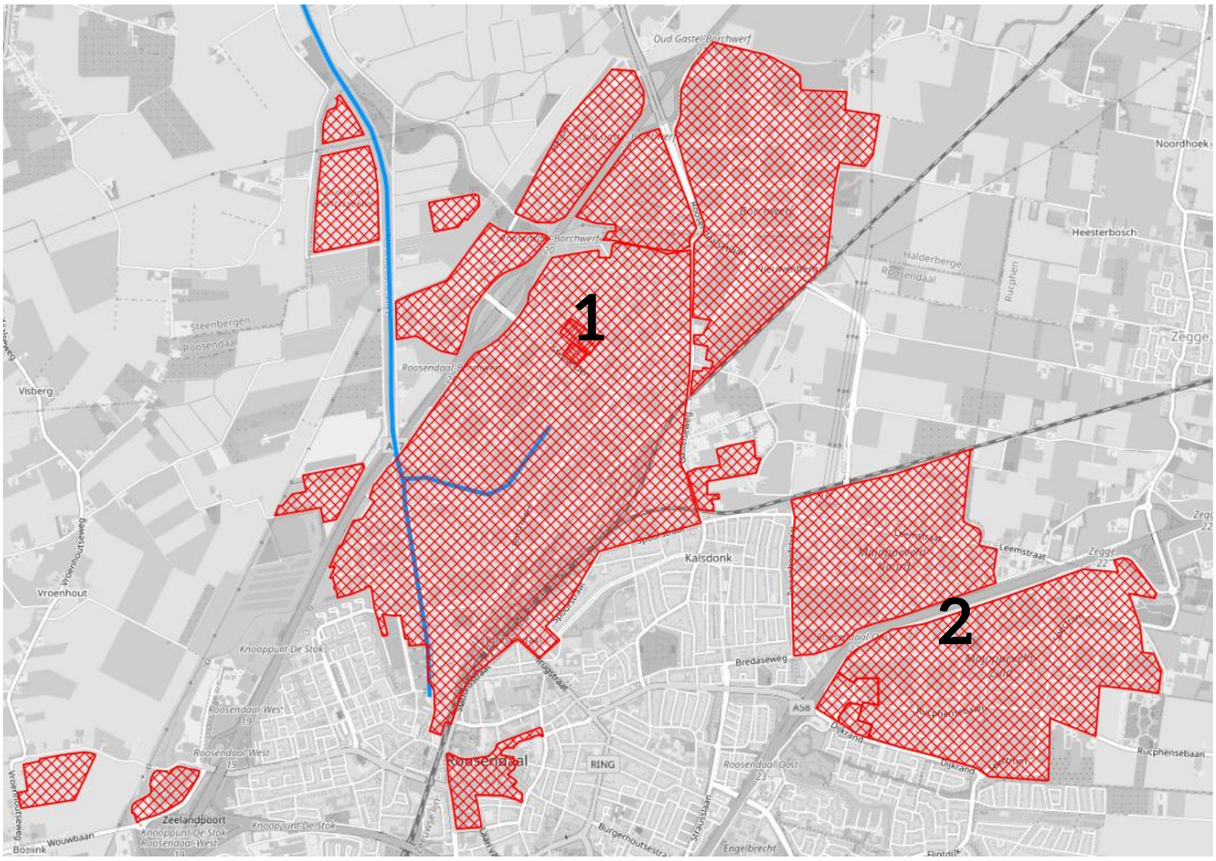

Figure 5-64: Industrial area(s) of Roosendaal
Map Data: OpenStreetMap, EuRIS

Looking at the waterway interface in the area, one will discover a total of 10 quayside companies (see Figure 5-65). Of these companies, only two entities seem to be actively using the quayside for waterborne transport of goods:

1. *Breure Grondwerken* (red #1 in Figure 5-64), a building-materials-supplier primarily engaged with "sand trade" (primarily import) in Roosendaal. Has one berth. See also the video here.
2. *Roosendaalse Asfalt Centrale* (red #2 in Figure 5-64), an asphalt production company and seem to be using the quayside primarily for import of materials for their production. It has two berths: a large and a small.

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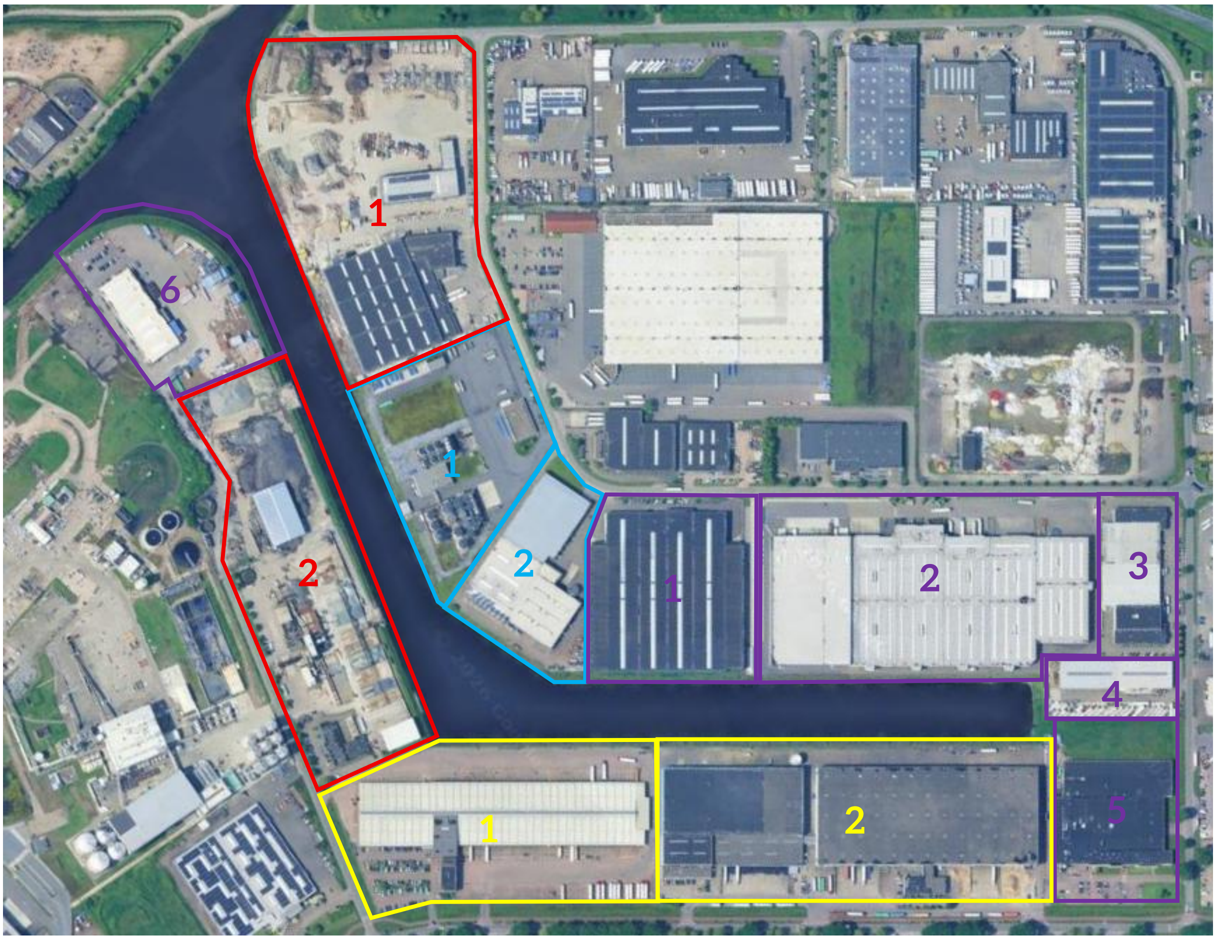

Figure 5-65 Roosendaal Potential modal shift clients
Maps data: © 2024 Google

Outside of these two terminals, there are no berths nor immediate quayside available. However, noticeable TPT locations could be:

1. The DHL premises (yellow #1 in Figure 5-65), with an open space close to the water that could potentially be used with a crane (reach stacker will probably not be able to reach over the "shrubbery" along the quayside with loaded containers). The premises are fenced off, which means access could be carefully controlled and given that the space is a DHL premise, it is fair to assume that storage capacity could be available inside of the distribution centre itself.
2. The Xorta Warehouse premises (yellow #2 in Figure 5-65), with an open space close to the water, fences off premises and available storage options, but also with the "shrubbery" issues vis-à-vis the potential use of reach stackers – all in all, more or less identical to the DHL case.
3. The Avista Oil premises (blue #1 in Figure 5-65), with a waterfront with seemingly hard overground upon which vehicles theoretically could operate.
4. The Modiform Extrusion premises (blue #2 in Figure 5-65), with a somewhat narrow but perhaps useable area near the waterway – at least from a hypothetical perspective. However, access to/from this waterfront area may be rather difficult, particularly for larger road vehicles such as trucks or similar.

In addition to these sites one finds *Konings Staal* – a steel supplier (purple #1 in Figure 5-65); *Imperial Logistics* - a larger logistics provider (purple #2 in Figure 5-65); *Packyard* NL – a printing company (purple #3 in Figure 5-65); Truck *Roosendaal* – a used truck dealership

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(purple #4 in Figure 5-65); *Cloetta/Lonka* – a candy manufacturer (purple #5 in Figure 5-65); and *K. Overdevest Transport* – a transport provider (purple #6 in Figure 5-65).

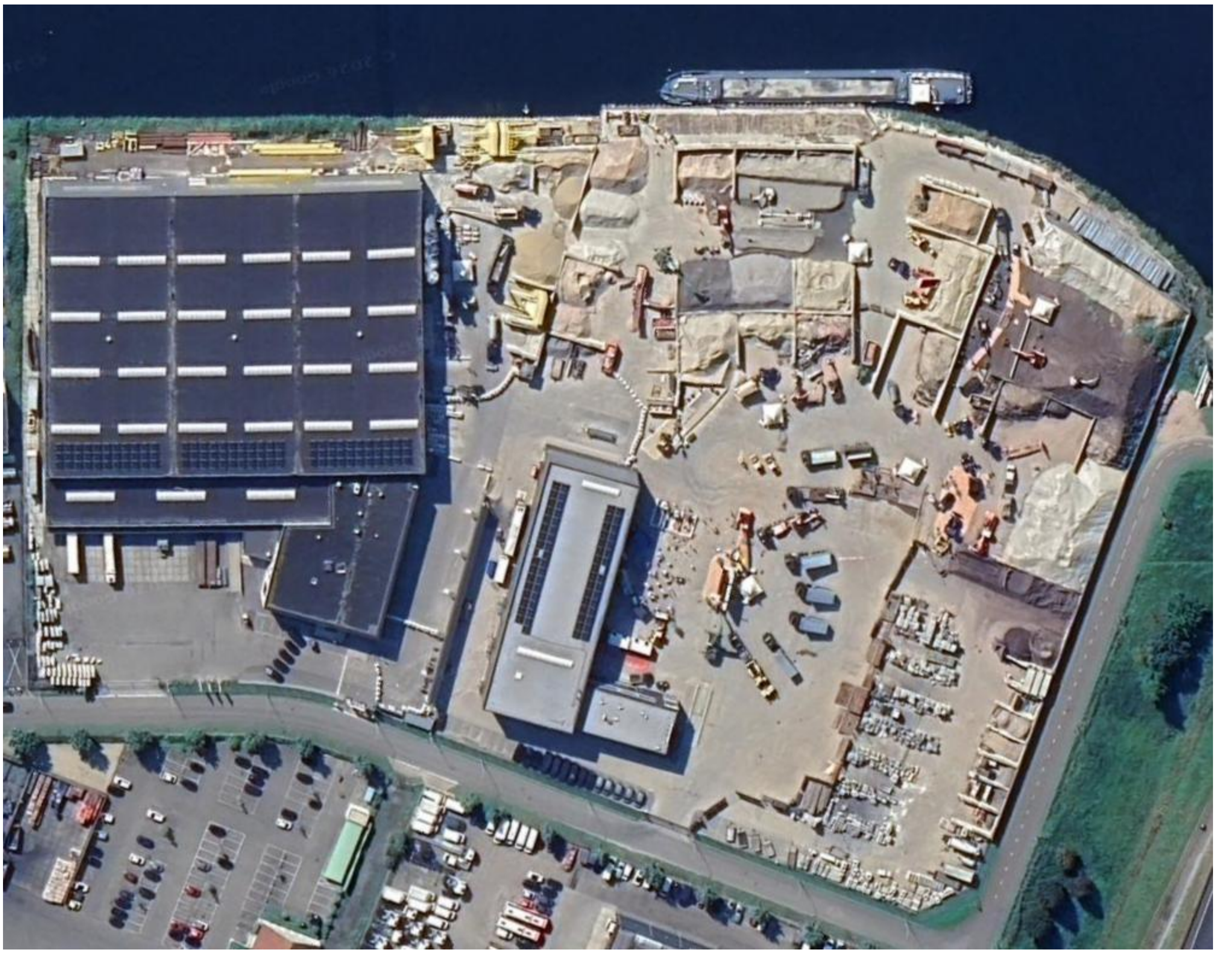

Figure 5-66 Breure Grondwerken (red #1 in Figure 5-65), Roosendaal
Maps data: © 2024 Google | © 2024 Airbus

Figure 5-67 Roosendaalse Asfalt Centrale (red #2 Figure 5-65)
Maps data: © 2024 Google | © 2024 Airbus

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Figure 5-68 The DHL premises (yellow #1 in Figure 5-65)
Maps data: © Google | © 2024 Airbus

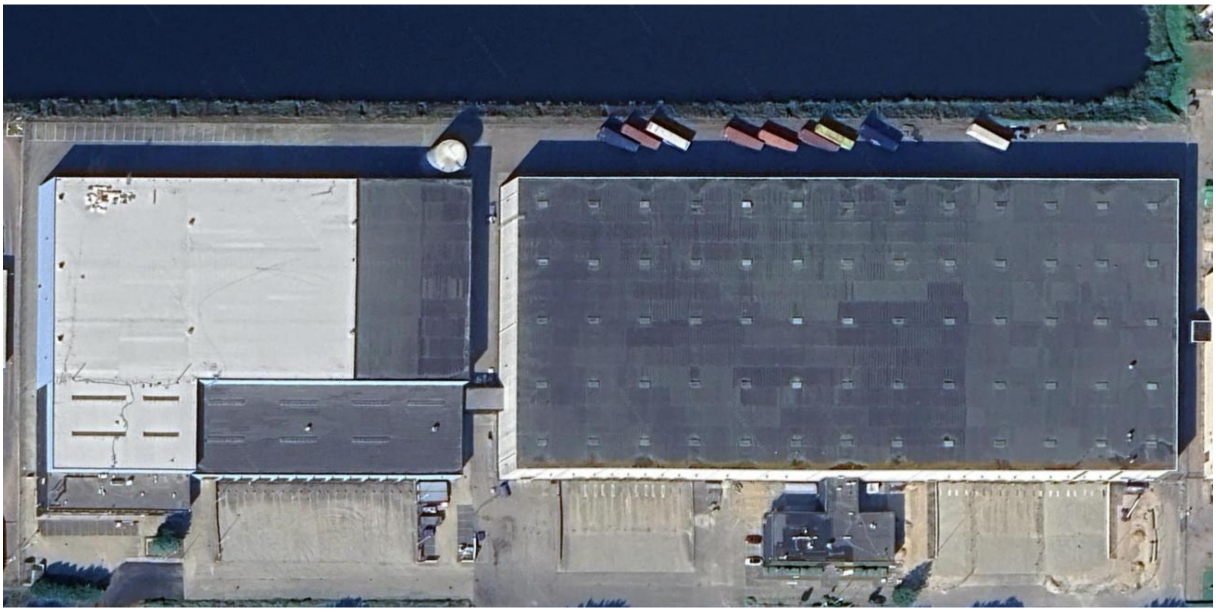

Figure 5-69 The Xorta Warehouse premises (yellow #2 in Figure 5-65)
Maps data: © Google | © 2024 Airbus

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Figure 5-70 The Avista Oil premises (purple #1 in Figure 5-65 and to the right in the above figure) and The Modiform Extrusion premises (purple #2 in Figure 5-65 and to the left in above figure)
Maps data: © Google | © 2024 Airbus

Given the “nature” of the IWT activities of both Breure Grondwerken (red #1) and Roosendaalse Asfalt Centre (red #2), it could be that these quays could be used by the logistics companies in the area at specific times whenever they are not in use by either of those two companies. This could for instance be, as argued multiple times within this analysis already, outside of their opening hours:

- Breure Grondwerken:
  - Monday – Friday: 06:00-17:00 (available for TPT operations 17:00-06:00)
  - Saturday: 07:30-12:30 (available for TPT operations 12:30-07:30)
  - Sunday: Closed (available for TPT operations all day)
- Roosendaalse Asfalt Centre:
  - Monday – Friday: 08:00-17:00 (available for TPT operations 17:00-08:00)
  - Saturday: Closed (available for TPT operations all day)
  - Sunday: Closed (available for TPT operations all day)

Of the two sites, Breure Grondwerken is of particular interest given its longer quay of ca. 70 meters in length, which gives ample space not only for the AUTOFLEX vessel to berth, but also for shore-based cargo handling equipment (e. g., a reach stacker) to operate along the entire length of the vessel without having to move the vessel along the quay (see Figure 5-66). In contrast, the Roosendaalse Asfalt Centre has two smaller quays: one of ca. 23 meters in length and one of ca. 12 meters in length (see Figure 5-67). Neither of these would hypothetically be long enough for the cargo handling equipment to access the entirety of the cargo of the berthed AUTOFLEX vessel. Consequently, of the two sites, Breure Grondwerken would be preferable for TPT operations, but that does not necessarily exclude the Roosendaalse Asfalt Centre from deploying TPT concepts nor from being used as an empirical case for the concept development.

In addition to these two premises, as mentioned, there are two larger logistical sites available near the waterfront which could potentially develop TPT operational capacities although not

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currently being engaged in waterborne transport. These sites are the DHL premises (see Figure 5-68) and the Xorta Warehouse premises (see Figure 5-69). Both sites are noticeable logistics hubs in the area, and as such could either develop their own TPT concepts directly from their premises or be tightly coupled to the TPT concepts developed at Breure Grondwerken and/or Roosendaalse Asfalt Centre. Should the DHL and/or Xorta sites themselves want to develop and deploy a TPT concept (e. g., for minimising the number of intermediates to the transport chain and thus, potentially, save on additional costs), they would first and foremost establish a way to tranship cargo over the overgrowth of plants the sites have along the waterfront. This overgrowth is ca 6 m wide, which would make it challenging for e. g., a reach stacker to reach out over the overgrowth to handle cargo from a berthed barge – especially for loaded containers, which could create a lot of momentum on the reach stacker arm. Furthermore, some sort of mooring concept would have to be deployed, as it is not entirely clear how the AUTOFLEX vessel should moor alongside this TPT due to lack of mooring bollards, -piles and -dolphins in the area. The Avista Oil and the Modiform Extrusion premises could also potentially be used for TPT purposes, as mentioned, but they too would have the same challenges with regards to transhipment and mooring as those mentioned for the DHL and Xorta premises.

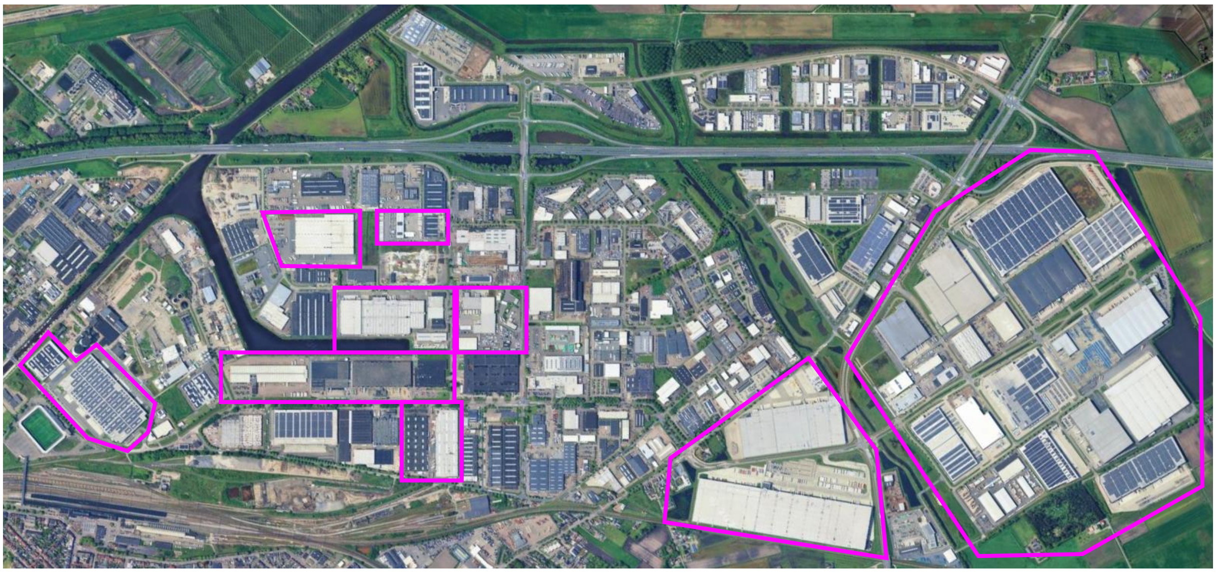

Figure 5-71 Logistics providers (pink) near the Roosendaal harbour basin
Maps data: © Google | © 2024 Airbus | © 2025 Airbus

On the waterfront itself, a total of three logistics providers (four if counting the Xorta warehouse), which indicates that Roosendaal indeed is an area with high volumes of transport goods. By uniting these sites around a TPT deployment would, potentially, form a concept in which last mile is more or less completely avoided. This is especially true for the case where DHL (or Xorta) manages to deploy a TPT directly within their own premises. When zooming further out, the picture becomes even more interesting. Figure 5-71 shows this zoomed-out view, highlighting the sites of logistics providers in pink (including the DHL, the Xorta and the Imperial Logistics premises near the harbour basin) and the other port actors. As can be seen from the figure, a noticeable logistics park can be found northwest of the Roosendaal port, with entities including ALDI Distribution Centre; Primark Distribution Centre; Lidl Online International Logistics Centre; CEVA Logistics; DHL Logistics; H.J. Bakker Logistics; Hollister Logistics; Forever Direct; Imperial Logistics; KOP Logistics; Nippon Express;

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RFT Logistics; and StreamLine Solutions. These may all be considered potential customers to the TPT deployment in Roosendaal, with minimal last mile (as the distance from the logistics park to the Roosendaal harbour basin area is around 3.5 km).

In conclusions, Roosendaal offers a strategically located industrial and logistics environment with direct access to a CEMT IV waterway, but only two quayside companies actively use the waterfront today – namely *Breure Grondwerken* and *Roosendaalse Asfalt Centrale*. While the former's longer quay makes it the most suitable location for TPT operations, the latter could still be used under more innovative mooring setups. Furthermore, several nearby premises (without ongoing transshipment operations) such as DHL, Xorta, Avista Oil, and Modiform could also support TPT concepts if challenges related to vegetation, mooring, and cargo handling are addressed. With a major logistics park only 3.5 km away from the harbour basin, along with multiple logistics providers situated directly along the waterfront, a coordinated TPT deployment could create a waterborne hub for the region with near zero last mile.

5.3.6. MSC CLUSTER 6: BREDA

In Breda, we find another larger industrial area surrounding a CEMT IV waterway, with a rail connection and highways A16 (running between Rotterdam and Antwerp) and A27 (running between Almere, just east of Amsterdam, and Breda). Especially the A16 is a heavily used and heavily congested road, particularly for freight vehicles connecting seagoing routes with short-sea routes from/to any of the two ports of Rotterdam and Antwerp. This means that a lot of road borne cargo would pass through Breda without necessarily stopping in Breda. From an IWT perspective, it is important to note that a stone's throw northeast of Breda is another location called Oosterhout from where IWT services already are available today. Thus, the industrial PoIs of Breda could potentially make use of these services already today.

At closer inspection, one finds a continuous industrial area close to the waterway that extends south-westwards a bit away from the waterway. The area lacks significant renewable energy production, available only in a small group of PV panels to the west of the waterway (yellow area). Hence, it does not seem likely that Breda will immediately be able to offer self-proficient energy to first/last mile vehicles and/or terminal equipment unless the energy comes from the grid or investments are made to erect more wind turbines and/or solar panels. For the purposes of this analysis, the industrial area of Breda is divided into three subareas: one concerning the northern smaller waterway "appendix" (area #1 in Figure 5-72 one larger area in *Haven de Krouwelaar* more central on the map (area #2 Figure 5-72 in and one in *Belcrumhaven* in the southernmost end of the waterway *Mark* running into Breda.

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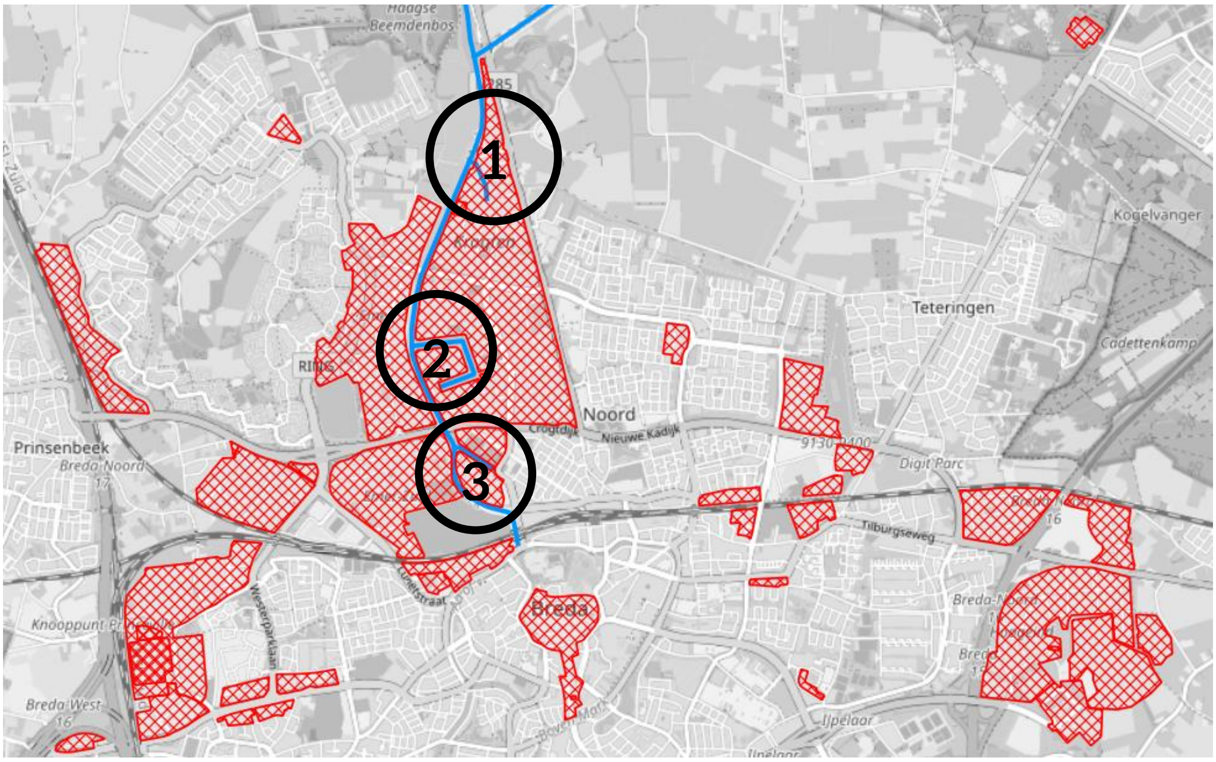

Figure 5-72 Industrial area(s) of Breda
Maps Data: OpenStreetMap, EuRIS

5.3.6.1. BREDA AREA 1: NORTH

In the northern interface area (i.e. area #1 in Figure 5-72), one finds an industrial site near an "appendix" to the *Mark* waterway running to/from Breda. In the vicinity of this "appendix", an industrial site can be found which is home to several points of interests, including:

- *Triferto Breda Terminal* – an active grain bulk terminal (red #1 in Figure 5-73);
- *Locomotion Watersport* – a water sport store and repair yard (red #2 in Figure 5-73);
- *Van Iersel Geveltechniek* – a windows supplier (red #3 in Figure 5-73);
- *Sando Puinrecycling* – a sand upcycler and wholesaler (red #4 in Figure 5-73);
- *Verhoeven* – a waste management service provider (red #5 in Figure 5-73);
- *Veem- en Overslagbedrijf* – a storage facility (red #6 in Figure 5-73);
- *Container huren MSB* – a container rental service provider (red #7 in Figure 5-73);
- *Michelin Distribution* – a distribution centre for the tire company *Michelin* (red #8 in Figure 5-73);

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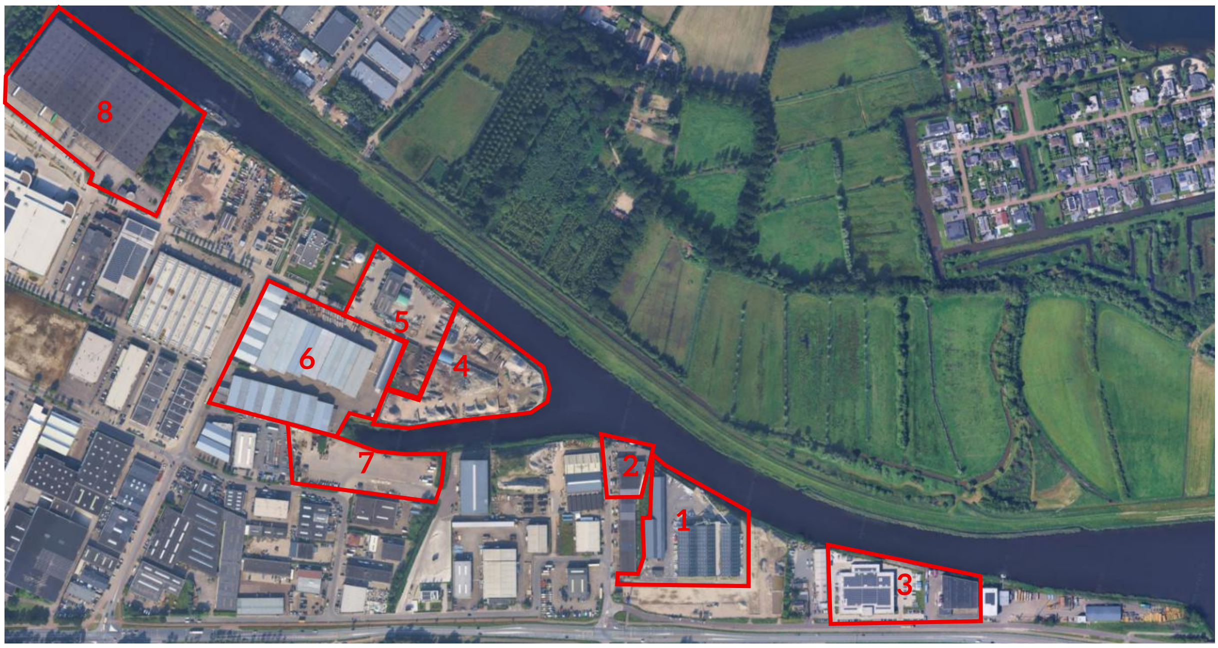

Figure 5-73 Subarea #1 (northern subarea) of Breda
Maps data: © 2024 Google

The only active transhipment terminal today is the *Triferto Breda Terminal*, which services ships carrying grain (red #2 in Figure 5-73). More detailed views of the site can be found in several images on the website found here. Triferto is an international wholesaler of mineral fertilizers and as can be seen in images on their webpages (e. g., click here), this fertilizer is often stored in large 600/1000 kg white bags. Although speculative, it appears that the Triferto Breda Terminal produces fertilizer in the larger "central" building and distributes this fertilizer in bulk via inland waterways vessels or in 600 or 1000 kg white bags via curtain-side trailers on trucks. While there is ground to assume that some of these white bags can be stored in containers and shipped over the IWT also, currently, the actual area on the quay upon which cargo handling equipment could be operated is relatively small. That is, the quay is only 12 meters long (of which half is already occupied by the bulk ship loader (the tract-looking device). Thus, if this location was to be used for container-based transhipments, the terminal operator would either have to invest in a fixed crane (such as a container crane or, perhaps, an RMG crane with extended reach, which would presumably drive up the CAPEX and thus make such TPT concept abnormally expensive if a sufficiently high amount of throughput can be secured), or have to invest in innovative mooring arrangements that would allow the vessel to be pulled backwards and forwards throughout the loading/unloading process (which, presumably, would also drive up CAPEX). Thus, the area may be relevant for the loading and unloading of merely a few containers which can be reached directly from the small quay space without investing in more advanced cargo handling equipment and mooring solutions. This may however still potentially be relevant for Triferto themselves as a way of transporting some of the 600/1000 kg white bags over the waterways instead of on the road. The area is fenced off, with a gate, which means that access control is already in place.

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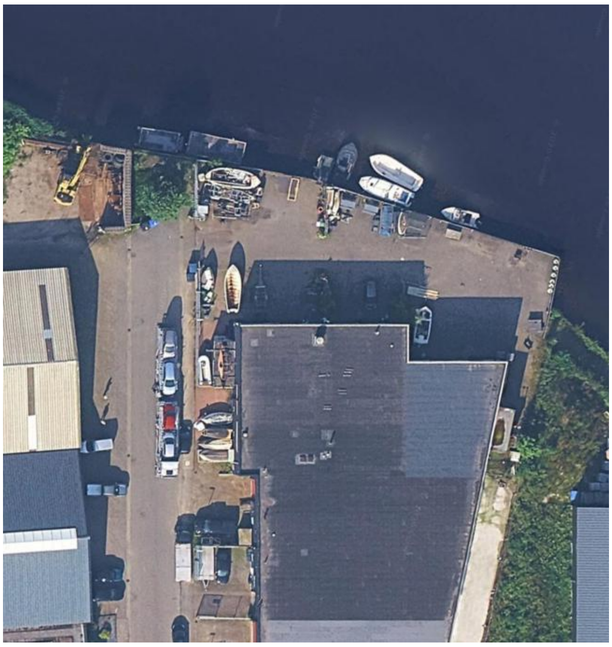

Figure 5-74 Locomotion Watersport
Maps data: © 2024 Google

At the *Locomotion Watersport*, the quay and adjacent potential terminal space are actively used for the storage, handling, and maintenance of recreational vessels and water sport accessories of various sorts – see Figure 5-74). Although the site displays characteristics that would theoretically support TPT activities (such as direct water access and sufficient quay length), its existing operational use occupies the far majority of the available waterfront space – and presumingly so on a more "permanent" basis. As long as these activities remain in place, it is difficult to fully envision the accommodation of TPT operations without directly displacing all or some of the core business of *Locomotion Watersport*. Only under a hypothetical scenario in which the boats and associated equipment are removed or relocated (either permanently or temporarily during the TPT operational hours) could the location become a viable TPT. This highlights a key limitation of the concept: while spatial and infrastructural suitability may exist in theory, actual feasibility is contingent on the compatibility of TPT operations with existing land uses and the willingness or ability of current actors to relinquish or share space, even on a temporary basis.

Figure 5-75 Van Iersel Geveltechniek (and adjacent, unidentified business)
Maps data: © 2024 Google

A third location that could theoretically accommodate a TPT is the *Van Iersel Geveltechniek premises* and its adjacent unidentified neighbouring business (see Figure 5-75). The site

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includes a quay of ca. 85 meters in length and 5 meters in width, which would theoretically be sufficient to berth the AUTOFLEX vessel of 55 metres and allow for basic transshipment operations. While the quay itself offers no meaningful space for cargo storage, this limitation could, in principle, be mitigated by temporarily repurposing the car parking areas of both the window supplier (and the adjacent business) for short-term cargo storage and/or buffering. However, satellite imagery does not clearly indicate ownership or control of the quay, introducing an additional layer of institutional uncertainty regarding access and use rights. Operationally, the location is further constrained by limited landside accessibility, with limited space for truck manoeuvring during container pick-up and drop-off, as well as by noticeable vegetation, particularly on the side of the window manufacturer, which would probably require removal or clearance for the concept to be optimal. Despite these constraints, the site could become viable under a targeted use case, especially if *Van Iersel Geveltechniek* itself were to act as a shipper, using the TPT to receive or dispatch windows in containerised consignments via the inland waterway directly from its premises. The area is fenced off and access is controlled through gates.

A fourth location with potential for deploying the TPT concept is *Sando Puinrecycling* – a sand upcycler and wholesaler that already appears to be engaged in bulk transshipment activities, see Figure 5-76. Satellite imagery shows a relatively long quay of ca. 100 m. in length and 7 m in width, which is actively used for handling dry bulk materials in line with the company's core operations. Immediately adjacent to the quay are several squared bulk storage compartments (four in total) which is used for the storage of sand or similar construction materials. While this configuration results in a relatively narrow operational corridor for additional terminal functions on the quayside, comparable layouts are commonly observed at inland bulk terminals and do not inherently exclude containerised transshipment activities. As the quay remains accessible from both sides of the bulk storage compartments, a one-directional circulation flow around these units could be setup to minimise congestion with multiple transhipment vehicles, if necessary. On-site container storage capacity is limited, as most of the premises are dedicated to the storage of the bulk commodities. However, this constraint could be mitigated through nearby off-site storage solutions. In particular, the adjacent Veem- en Overslagbedrijf storage facility (red #6 in Figure 5-73) offers readily accessible storage capacity via a convenient "internal" road connection (i.e. not accessing public roads per se). The Sando Puinrecycling and the Veem- en Overslagbedrijf premises can be seen on Figure 5-76. Alternatively, logistics customers within the industrial area, such as the Michelin Distribution Centre (red #8 on Figure 5-73), could store containers at their own premises and have them moved to the quay only shortly before loading or after unloading. In this configuration, the TPT would function analogously to a seaport terminal that spatially separates quay operations from storage areas, using different zones for containers based on consignee or consignor, destination, or cargo type. Rather than concentrating storage within the terminal footprint itself, the TPT could leverage surrounding industrial actors as distributed storage nodes, some of which may simultaneously act as logistics customers. This ecosystem-based storage model has the additional advantage of potentially eliminating last-mile transport altogether, as containers can be handled directly between vessel and nearby end users. The proximity of the Container huren MSB facility (red #7 in Figure 5-73) further strengthens this configuration by providing both container rental services and potential supplementary storage capacity. Compared to locations such as the Triferto Breda Terminal, Sando Puinrecycling may represent a more favourable TPT site due to its longer quay and immediate access to multiple forms of off-site storage. This case also introduces an important conceptual distinction within the TPT framework between locations with sufficient "on-site storage" capacity and those that rely on

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distributed, "off-site storage" embedded within the surrounding industrial ecosystem. The Sando Puinrecycling premises is fenced off with access control by gates.

Figure 5-76 Sando Puinrecycling (left) and Veem- en Overslagbedrijf (right)
Maps data: © 2024 Google

5.3.6.2. BREDA AREA 2: HAVEN DE KROUWELAAR

In the central area known as *Haven de Krouwelaar*, several potential applications for the TPT concept can be identified, see Figure 5-77. For the purposes of the narrative presentation in this section, the area is divided into the *Haven de Krouwelaar* itself and the waterways *outside* the *Haven de Krouwelaar* (which is effectively the *Mark* waterway itself). Historically, Breda used to be the place of a larger fish market due to its direct waterborne shipping connection with the sea towns of the Netherlands, and it is not farfetched to imagine the *Haven de Krouwelaar* to be a central place for this market and fish trade. Today, for the purposes of this report, six sites stick out and require deeper analysis.

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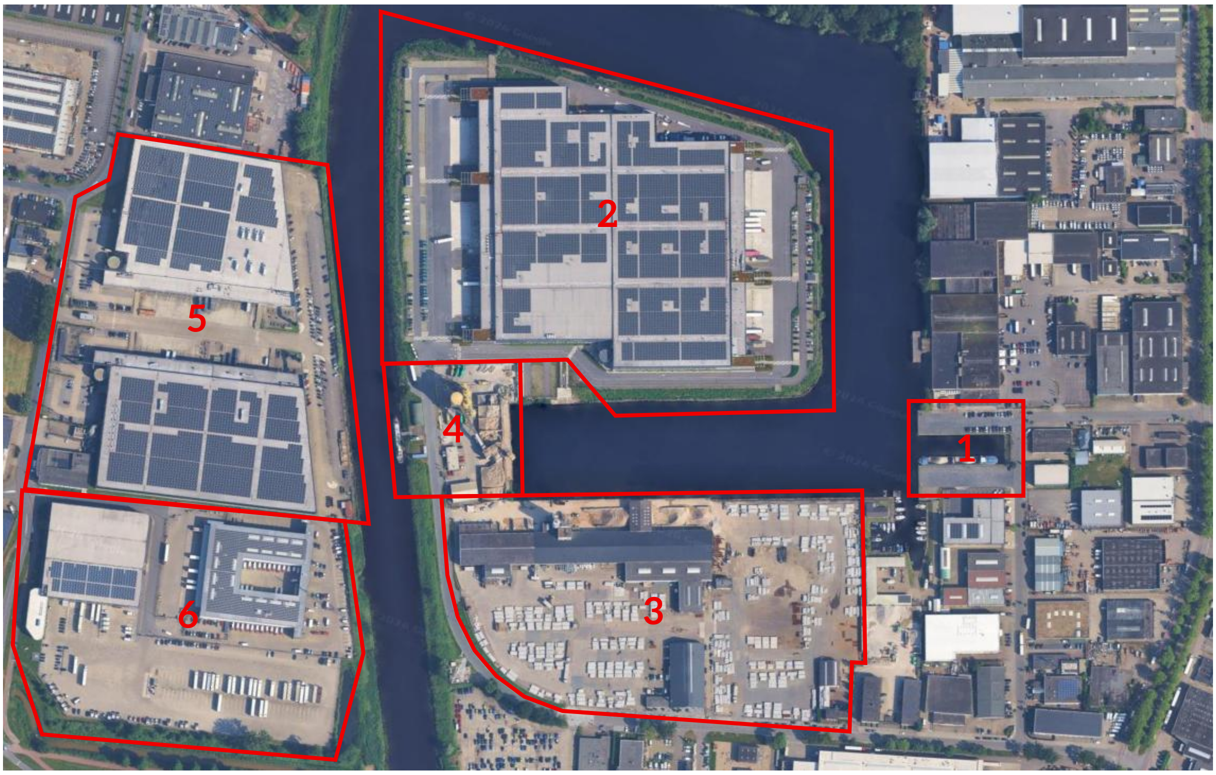

Figure 5-77 Subarea #2 (Haven de Krouwelaar) of Breda
Maps data: © 2024 Google

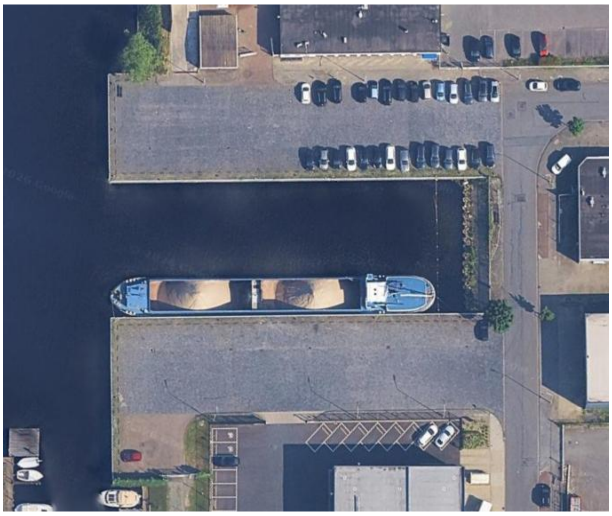

Figure 5-78 The Karlshoven pier
Maps data: © 2024 Google

First, within the basin itself, the *Karlshoven* pier stands out as a particularly interesting TPT site capable of injecting containerised cargo directly into the surrounding area, potentially through a part load consolidation or distribution model serving the many smaller actors in its vicinity. The *Karlshoven* pier is marked as red #1 on Figure 5-77 and can be seen in detail in Figure 5-78. At present, however, it does not seem that the nearby businesses are strongly logistics-oriented, which raises uncertainty regarding immediate demand for transshipment activities at the *Karlshoven* pier. Should interest materialise, the characteristics of *Karlshoven* are favourable: the basin is approximately 75 metres long and 25 metres wide, theoretically allowing two AUTOFLEX vessels to be accommodated simultaneously. On each side of the basin lies two almost identical operational areas of roughly 20 metres by 78 metres, equating to approximately 1.500 square metres of hard-surfaced space per side. The uniformity and robustness of the surface, together with its configuration, indicate that the site probably has been used for transshipment historically rather than merely as a temporary mooring or parking area as it appears to be today. The absence of fencing around the perimeter of the site implies that any TPT deployment would require careful operational and safety planning to avoid conflicts with residential or public access. In terms of storage capacity, the two 1.500 square metre area could accommodate a fair share of containers across both sides of the basin, which suggests

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that, from a spatial and infrastructural perspective, *Karlshoven* could support a meaningful TPT operation, provided that sufficient interest from nearby logistics users can be established.

Another potential TPT location is the *Brand Masters* site – a company specialising in connecting international A-brands with non-food retailers and operating a relatively large distribution centre that relies heavily on truck- and van-based logistics. The *Brand Master* site is marked as red #2 on Figure 5-77 and can be seen in detail in Figure 5-79. From a logistics perspective, this profile makes *Brand Masters* a potentially attractive customer for the AUTOFLEX system, as inbound and outbound flows are already consolidated at a single location. At present, however, the site's entire waterfront is heavily overgrown with vegetation, which prevents direct transshipment operations as-is. Selective clearance and redevelopment, particularly along the northeastern waterfront facing *Haven de Krouwelaar*,

Figure 5-79 The Brand Master site in Haven de Krouwelaar (Breda)
Maps data: © 2024 Google

could enable quay access in a location that aligns closely with existing truck access and, presumably, internal logistics flows. In terms of storage, it is reasonable to assume that *Brand Masters* possesses sufficient on-site warehousing capacity, allowing the potential inland waterway transport to be fully integrated with its road borne distribution activities. Access control at the site is strong: the perimeter is fenced and only accessible by land via a controlled gate at the entrance, which monitors and manages visitors. While ISPS requirements do not formally apply to inland terminals, this configuration aligns well with comparable security expectations. Satellite imagery further indicates extensive coverage of PV panels on the roof

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of the building(s), which could potentially support electrically-operated terminal equipment and, potentially, if not already available, electrically-operated last mile vehicles. Consequently, although the *Brand Masters* site is not immediately suitable for TPT deployment, targeted redevelopment of its northeastern waterfront (right side in Figure 5-79) could result in a highly integrated TPT concept directly embedded within, or even exclusively serving, the company's existing logistics operations. The feasibility of such a configuration ultimately depends on the balance between required infrastructural investments and achievable logistics benefits. This introduces an additional evaluative parameter for the TPT concept: whether the costs of enabling transshipment through infrastructural redevelopment can be amortised over a commercially acceptable period while maintaining competitive transport prices. If a location requires redevelopment to such an extent that such investment costs become that transport prices can only remain competitive if amortisation happens over an exacerbated period of time, then the concept would be financially impractical. Conversely, if costs can be recovered within a limited number of years through improved logistics efficiency and environmental performance resulting from modal shift via AUTOFLEX, the site would represent a highly feasible TPT application.

Figure 5-80 The Dycore site in Haven de Krouwelaar (Breda)
Maps data: © 2024 Google

The third potential TPT location within Haven de Krouwelaar is the Dycore site (de RuwBouw Groep), a cement contractor with extensive outdoor storage areas containing narrow precast concrete elements, likely used in modular wall and floor construction systems. The *Dycore* site is marked as red #3 on Figure 5-77 and can be seen in detail in Figure 5-80. The site is already actively engaged in waterborne transshipment, presumably of concrete-related bulk inputs given the nature of the Dycore company activities. Historical satellite imagery indicates that this transshipment activity has been in place for several years and reveals an operational setup that does not rely on a fixed quayside crane (see Figure 5-81). Instead, cargo handling appears to be performed using cranes mounted on barges moored alongside the quay – potentially as simple a setup as "merely" a digger located on a floating pram. This configuration is particularly relevant for the TPT concept, as it demonstrates that

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cargo handling capacity does not necessarily need to be fixed ashore but can also be provided as a floating, mobile asset. Such an approach introduces an additional dimension to the TPT model, in which handling equipment can be deployed on barges and repositioned between locations as needed, making it especially suitable for sites with limited quayside space or where permanent installations are undesirable. This logic could potentially be extended to storage functions as well, where barges can be used as temporary or modular storage units moored along the quay, or even combined transshipment-and-storage barges functioning as self-contained terminal modules that provide both transhipment and storage functions. This water-based modularisation of terminal functions would allow TPT deployments to incrementally scale operational scope and throughput without significant investment in shoreside infrastructure. However, in the case of Dycore, the site offers substantial on-site storage capacity amongst the precast concrete elements, some of which could potentially be containerised if weight and dimensional constraints allow. Even where containerisation is not feasible, the AUTOFLEX vessel could still potentially be used to transport these precast elements directly by water and tranship them at the site. The perimeter of the Dycore site is fenced, enabling controlled access, although seemingly not through a formal gate structure similar to Brand Masters' premises. The existing bulk terminal is already spatially separated from the main production and storage areas, suggesting that a similar spatial separation could potentially be created in the north-eastern corner of the site (right side on Figure 5-80 and Figure 5-81) to accommodate a container-oriented TPT without disrupting ongoing operations. Furthermore, as can be seen in Figure 5-80, marked by the white circle, the site has equipment for handling the concrete blocks. While this equipment might need an upgrade to be able to handle containers, or even if it would have to be replaced, it is possible to imaging a setup where a TPT established here could share assets such as cargo handling equipment with Dycore. Even though that would imply tight coordination with the daily operations of Dycore, it could be an attractive solution as it would bring down the cost of establishing and operating a TPT here.

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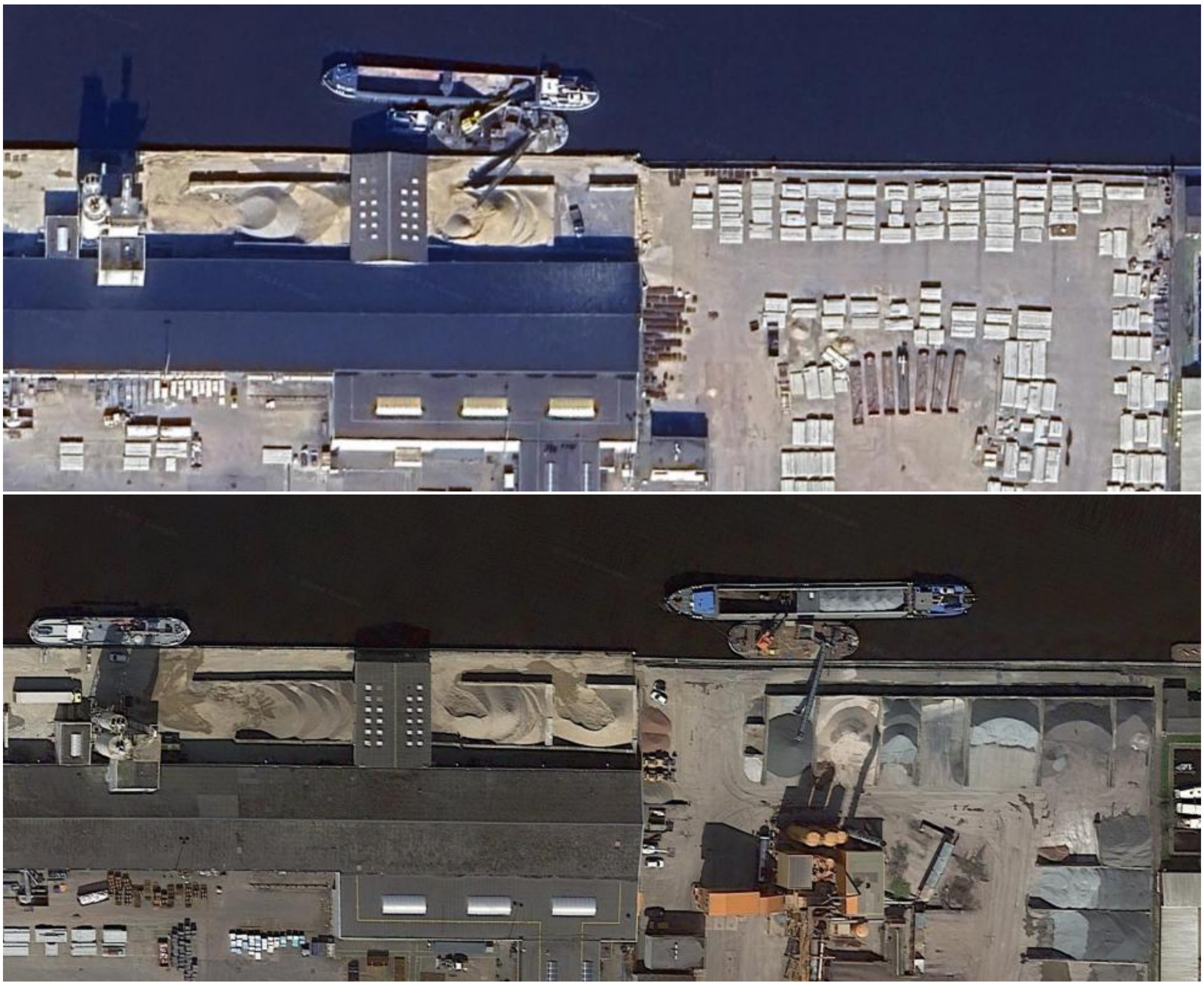

Figure 5-81 Transhipment activities at the Dycore site (top: 2025, bottom: 2018) in Haven de Krouwelaar (Breda)
Maps data: © Google (both) | © 2025 Airbus (top) | © 2018 Google (bottom)

Another site of interest in the *Haven de Krouwelaar* area is the *Mebin* premises – a cement supplier located right next door to the *Dycore* terminal, see Figure 5-82. The site resembles many conventional inland bulk terminals, featuring approximately 80 metres of berthable quayside. Today, only 65 metres of the quay are actively used for transshipment activities, which together with a width of around 6 meters, makes the transhipment area. This area is occupied by a rail-mounted gantry (RMG) crane running on tracks along the quay. Directly behind this area are cement storage compartments similar to those observed at the Sando and Dycore sites. However, unlike those locations, there are no direct access to the quayside next to these compartments at the *Mebin* site. This configuration significantly constrains the site's suitability for containerised transshipment, as the existing crane lacks the reach and flexibility to handle containers beyond the bulk storage areas, and road vehicles are unable to approach the quay closely enough to facilitate container handling. As a result, deploying a TPT at this location would likely require substantial investment, either through replacing the existing crane with a multipurpose handling system capable of serving both bulk and container cargoes or through more fundamental reconfiguration of the quay layout. Such investments would be considerable and may prove difficult to amortise within a commercially acceptable timeframe, particularly given the site's strong orientation towards bulk operations. Opposite the Mebin terminal lies the Titus

Figure 5-82 The Mebin site in Haven de Krouwelaar (Breda)
Maps data: © Google | © 2024 Airbus

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Breda water cruise company, which operates touristic services along the Mark waterway. While this activity is not directly relevant to a TPT application, it does suggest the presence of additional mooring infrastructure along the waterway that may not be immediately visible from satellite imagery, indicating that mooring of vessels may be more accessible than first anticipated.

Moving beyond *Haven de Krouwelaar* and onto the *Mark* waterway itself, another highly promising location for a TPT can be identified at the *DB Schenker* distribution centre. The site is marked as red #5 in Figure 5-77 and can be seen in detail in Figure 5-83. Although the site does not currently make use of IWT, it features a seemingly intact quay of approximately 285 metres in length, of which the southernmost 120 metres is relatively unobstructed by vegetation compared to the more overgrown northern section. The quayside area measures roughly 32 metres in width, resulting in an estimated 9,000 square metres of potential operational space, which would be more than sufficient to accommodate both transshipment activities and on-site container storage within the TPT concept blueprint. This space would most likely also be naturally integrated with the DB Schenker distribution centre activities themselves and thus offer substantial additional warehousing capacity. At present, the waterfront is used almost exclusively for private car parking (assumingly for DB Schenker personnel) and does not appear to serve any logistics-related function. From historical satellite imagery, the parking is never filled more than what can be observed in Figure 5-83, thus indicating that parking needs could be satisfied with substantially less use of the space. The premises is fenced and access-controlled in a manner comparable to conventional port terminals, suggesting that, while not mandatory for inland terminals, compliance with more advanced ISPS-style security regimes could be achievable and may even enable accessibility for seagoing vessels. Immediately south of the site are the Breda depots of PostNL and Nouwens Transport (red #6 in Figure 5-77), introducing further potential transport users and, if required, supplementary storage capacity within close proximity. Taken together, the combination of extensive quayside space, strong access control and seamless integration potential with an existing large-scale distribution centre makes this a particularly compelling TPT location, requiring only relatively limited waterfront redevelopment to unlock its full potential within a broader logistics network anchored by DB Schenker.

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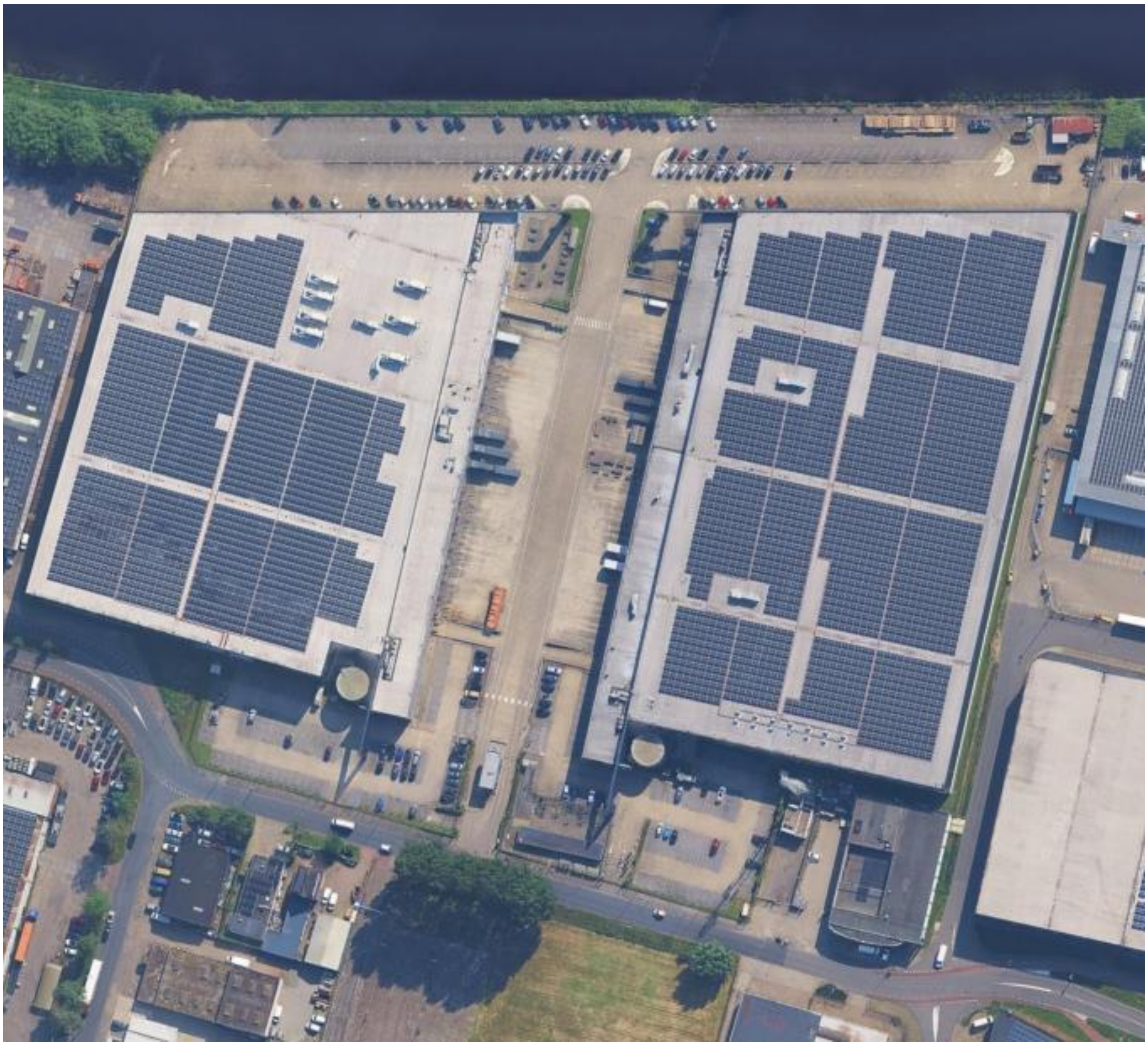

Figure 5-83 The DB Schenker premise near Haven de Krouwelaar (Breda)
Maps data: © 2024 Google

5.3.6.3. BREDA AREA 3: BELCRUMHAVEN

In the last and southernmost subarea of Breda lies the *Belcrumhaven* port: a largely decommissioned harbour area now characterised by two distinct land-use patterns. One former industrial terminal has been redeveloped into a leisure area hosting a skatepark, restaurants, and other public amenities, along with a crane company, while another former industrial site remains largely vacant, aside from a central building with various smaller businesses and a restaurant. Within the leisure-oriented section of Belcrumhaven, several commercial vessels are moored along the quay. This do however appear to function primarily as long-term parking rather than as part of active logistics operations, as no transshipment activities are evident. A crane service provider operator can be found in the area, the *Manitowoc Crane Group*, and although the specific crane types present on site are not known, their presence introduces an interesting opportunity for the TPT concept: existing cargo-handling equipment could potentially be leased on a temporary basis when not required by *Manitowoc* itself. This would enable an asset-light terminal configuration in which the TPT owner leases locally available equipment and subleases it to the TPT operator, avoiding the need for upfront investment in cranes while simultaneously incentivising local equipment

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owners to activate otherwise idle assets. The quay in this section offers approximately 215 metres of usable length and around 8 metres of operational width (excluding the adjacent road), providing sufficient space for transshipment activities and some container storage. Transhipment activities could even be done while still allowing part of the quay to be used for moored vessels. The area is currently unfenced, which would necessitate careful coordination of security and safety measures to prevent conflicts with public access. Next to this is a larger building (to the right in Figure 5-84) which belongs to the company *Nemijtek* – a storage and transshipment company for frozen and refrigerated raw materials and products. Thus, if the TPT concept at this site would allow for transshipment of reefer containers, i.e. containers that are cooled during transport, this site could well integrate into a larger European IWT supply chain. However, such containers can only be carried in small numbers, around 4 units, by the AUTOFLEX vessel.

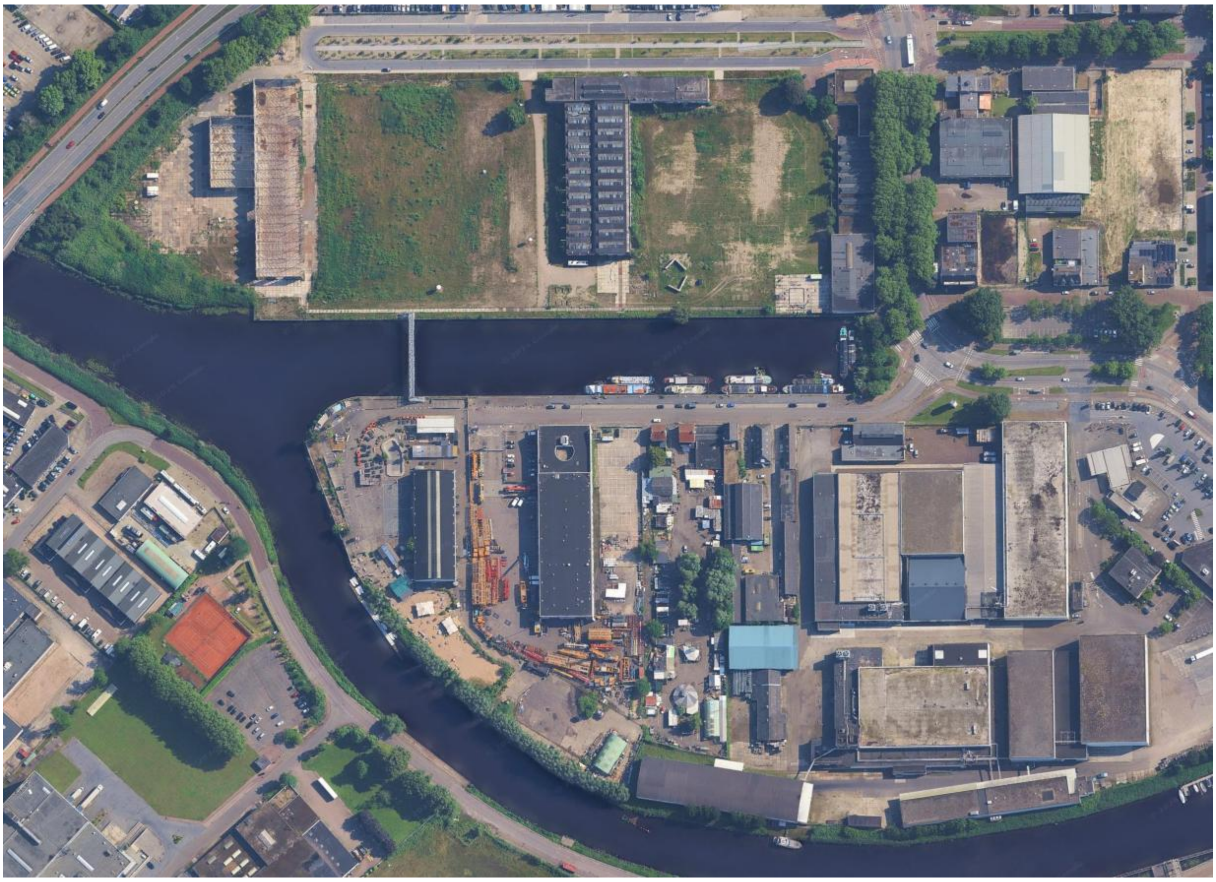

Figure 5-84 Belcrumhaven (Breda)
Maps data: © 2024 Google

On the opposite side of *Belcrumhaven* lies a largely abandoned brownfield site that, based on historical satellite imagery, supported substantial industrial activity until approximately 2017, after which the two large industrial buildings were removed. Although the area is now significantly overgrown, the quay itself appears to remain structurally intact. This would however need to be verified following clearance of the vegetation. The quay extends nearly 350 metres in length, theoretically allowing multiple vessels to be accommodated simultaneously if it was restored for transshipment use in its entirety. On each side of the remaining central building, i.e. where the two larger industrial building used to stand, are now two sizeable brownfield areas of approximately 21.000 and 14.000 m^2 which offers significant storage opportunities. One could even imagine a phased development strategy in

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which only one of these areas are activated during the initial TPT deployment, with the other areas also developed if the TPT concept proves successful and scalable. The site also appears to remain fenced, albeit potentially in a degraded condition. Taken together, the Belcrumhaven area illustrates an additional dimension of the TPT concept: an asset-light, low-entry-barrier mechanism for testing the logistical and commercial viability of dormant or underutilised port infrastructure before committing to permanent investments in terminal equipment and full-scale redevelopment.

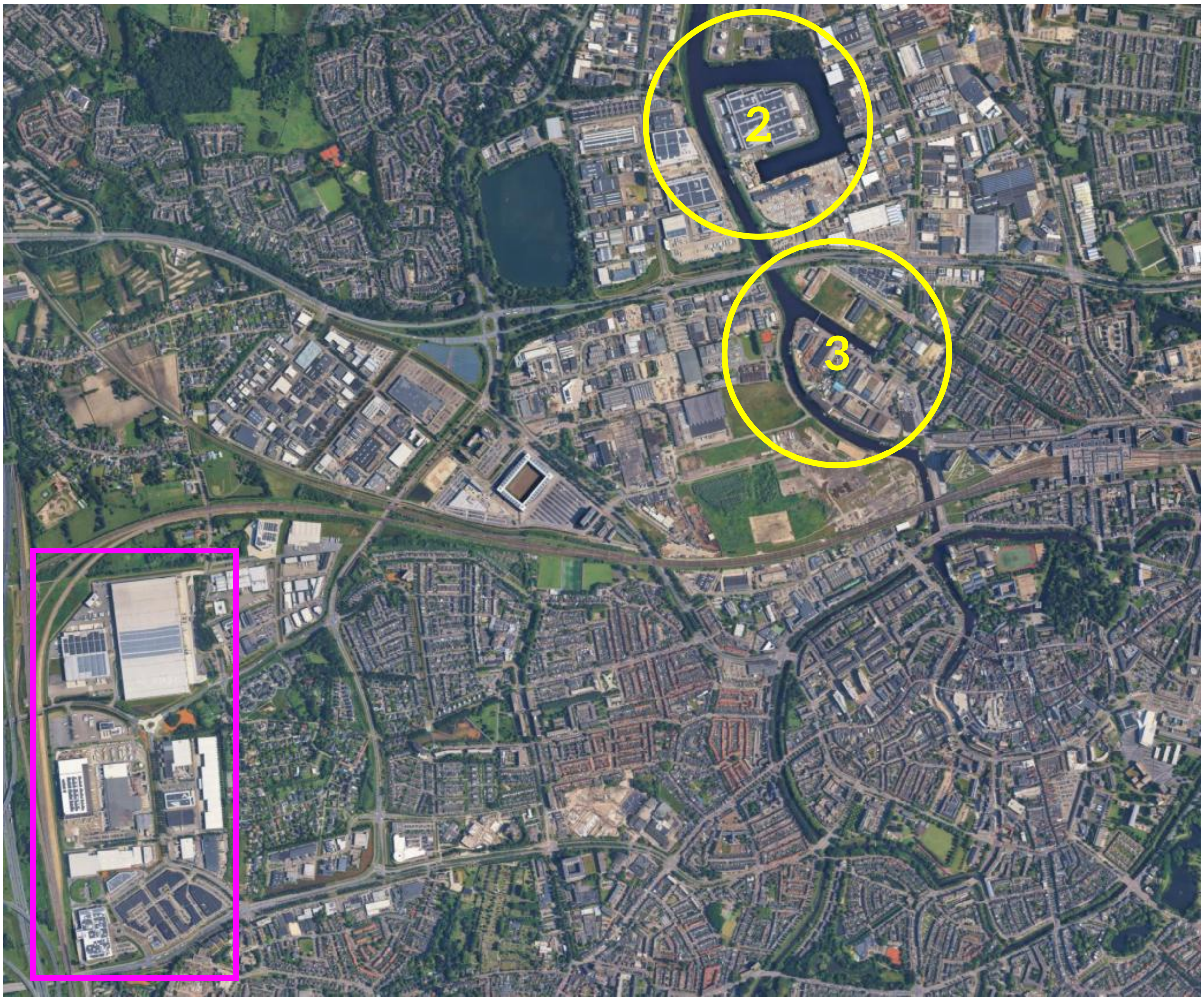

Figure 5-85 Large industrial site (pink) in proximity to the Haven de Krouwelaar (yellow #2) and Belcrumhaven (yellow #3)
Maps data: © Google

From the perspective of potential inland waterway transport (IWT) customers and, by extension, prospective TPT users, a large industrial and logistics compound is located in close proximity to both Haven de Krouwelaar and Belcrumhaven (see Figure 5-85). This cluster includes a major Lidl distribution centre, a dedicated Zachtfruit distribution facility, and the Jumbo Breda Distribution Centre, alongside two large IKEA storage facilities and a conventional IKEA retail store, as well as several smaller commercial establishments. Collectively, these actors represent substantial and relatively stable logistics volumes that could complement the already significant flows expected from DB Schenker. The presence of this concentration of distribution and storage activities strengthens the case for developing waterborne logistics services in the area and may ultimately justify the establishment of a

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full-time, fixed inland port terminal in Belcrumhaven. In this context, the TPT concept can be understood as a transitional mechanism that lowers entry barriers by enabling demand for transshipment and IWT services to be tested, validated, and incrementally scaled in practice before committing to permanent infrastructure investments. By allowing capacity to be flexibly adjusted in response to observed demand, the TPT can serve as a first stepping stone from ad hoc or pilot operations toward a structurally embedded inland terminal, should sustained cargo volumes from these surrounding logistics centres materialise.

5.3.7. MSC CLUSTER 7: EINDHOVEN

In Eindhoven, one finds an array of industrial landuses sporadically located throughout the area, with a CEMT II waterway and a large rail network available as alternative transport modes.

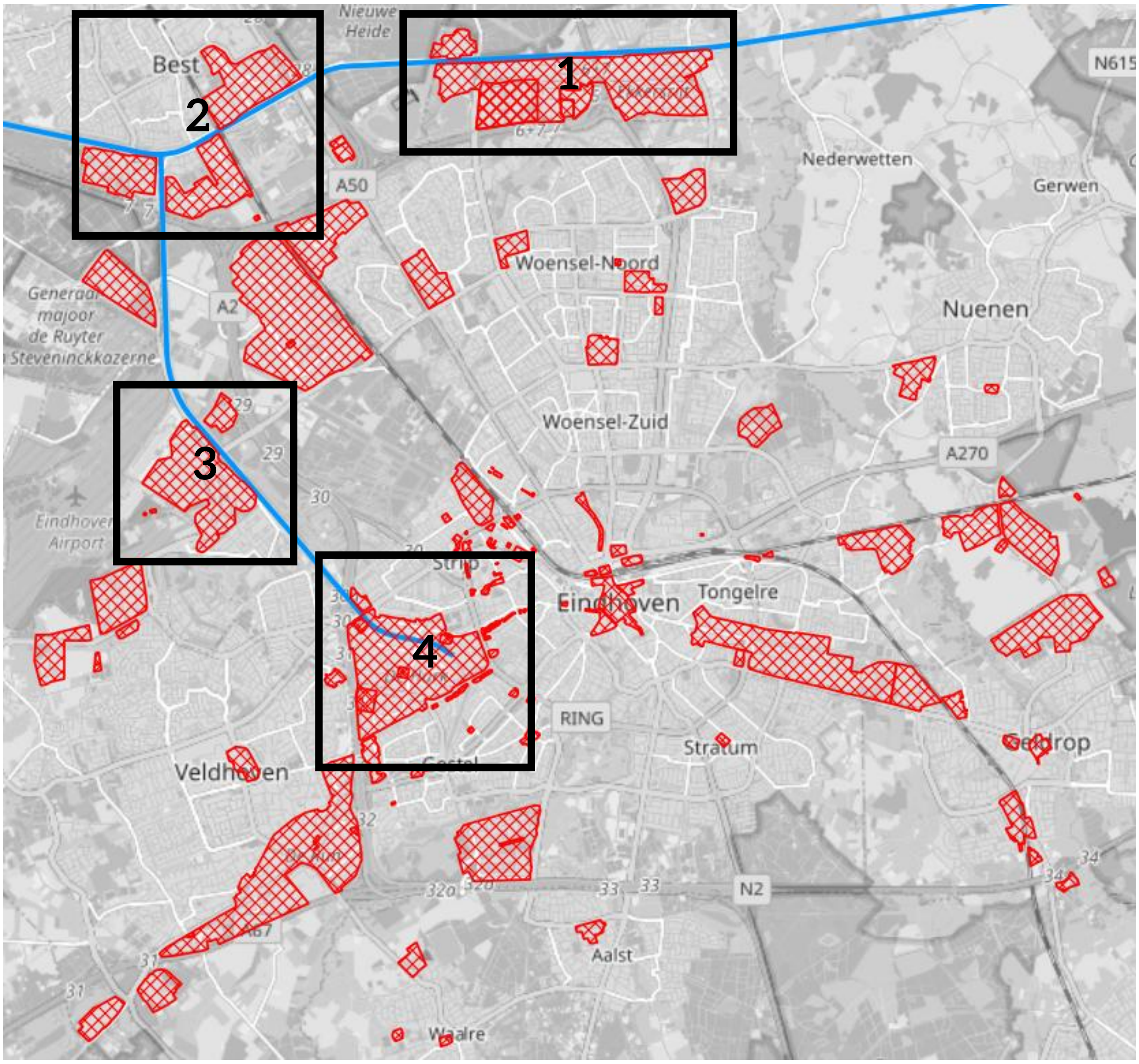

Figure 5-86 Industrial area(s) of Eindhoven
Map Data: OpenStreetMap, EuRIS

At closer inspection, one finds a few different potential areas with industrial sites next to the water; however, few of these areas could be useful for transshipment purposes. These areas have been marked as 1, 2, 3 and 4 respectively in Figure 5-86.

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5.3.7.1. EINDHOVEN AREA 1: EKKERSRIJT

Area 1, located north of the Eindhoven city in the industrial area of *Ekkersrijt*, consists of a centralization of a few industrial and commercial subdivisions of different characteristics. First, the largest single entity in the region is a large Rhenus distribution centre (red #1 Figure 5-87). directly located next to the waterway. Second, next to the Rhenus location, is a Ubiquity distribution centre (red #2 Figure 5-87), Third, are various "bundles" of mixed commercial and industrial activities, namely a few second-hand truck and car dealerships and various commercial activities (e. g., an IKEA store). Fourth, are two distribution centres located west of the Rhenus location: a warehouse by DP World and the Lekkerland Distribution Centre (pink #1 and #2 Figure 5-87 respectively). When inspecting the site(s) more in depth, one will find that two potential transshipment sites occur where the TPT concept could potentially be deployed.

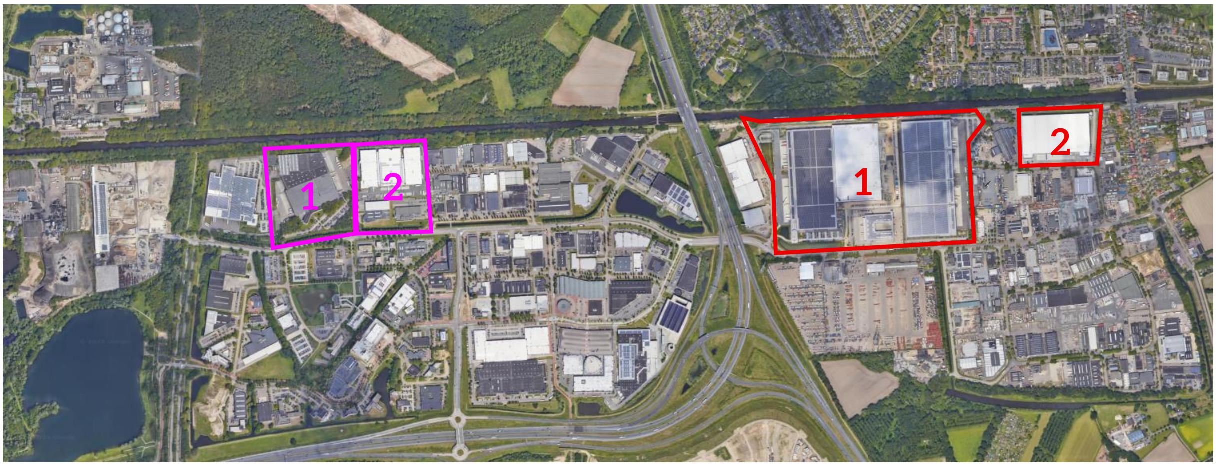

Figure 5-87 Overview of industrial area in Ekkersrijt, north of Eindhoven
Maps data: © Google

First, adjacent to the Ubiquity distribution centre (red #2 in Figure 5-87), a long and largely abandoned stretch of quay infrastructure can be identified (see Figure 5-88). This presents another potential application for the TPT concept. The total length of this quay is approximately 440 metres – however, a central section of around 100 metres (located roughly opposite the core of the Ubiquity site) is relatively free from dense vegetation and would already be sufficient to accommodate the 55-metre AUTOFLEX vessel. At present, this section appears to be used informally as temporary parking space for trucks and other vehicles (see Google Street View here), but there is little indication of systematic or intended use. It is also unclear whether the quay forms part of the Ubiquity premises or constitutes an independent piece of infrastructure, potentially under municipal ownership, as a public road runs between the distribution centre and the waterfront. This ambiguity implies that the site could, in principle, be activated for TPT purposes without direct reliance on Ubiquity's consent. While both ends of the quay are currently overgrown, the central section could be brought into operation with minimal intervention, as the presence of mooring bollards suggests that the quay remains structurally serviceable. Historic Google Street View (here) photography also shows that leisure craft are occasionally moored to the quay here. Should the TPT prove successful, the concept could be incrementally expanded by clearing vegetation at either end and, if necessary, reinforcing the quay surface where degradation has occurred. Although the site itself offers limited space for container storage, it is well positioned within an industrial context in which adjacent logistics actors could effectively function as distributed storage

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nodes, treating the surrounding industrial area as a shared TPT ecosystem (in line with earlier comment on such configuration's similarities to existing operational architectures in seaports). In such a configuration, containers would be stored and, ideally, prepared for shuttling, at the users' own premises and transferred to the quay shortly before loading (or, in import cases, shortly after unloading), reducing the need for dedicated on-site storage. Some "buffer space" near the quay may still be required to store a few containers to prevent operational downtime, which may prove challenging in this case given the modest waterfront area unless coordination is tightly managed or the open grass area immediately north of the Ubiquity site is upgraded to a hard-surfaced buffer zone. The site is currently unfenced, meaning that access control is limited and that any TPT deployment would need to account for potential interactions with third parties using the public road or adjacent areas. Nevertheless, given the industrial character of the surroundings and the apparent lack of recreational use, it may be feasible for the local authority to permit temporary or permanent fencing across the road, particularly as alternative access routes exist within the industrial estate and thus the blockage of the road would have minimal effect on the general "mobility" in the area. Overall, this location represents an attractive and readily deployable TPT site that could be activated almost immediately and scaled progressively along the full 440 metres of quay if demand for transshipment services materialises.

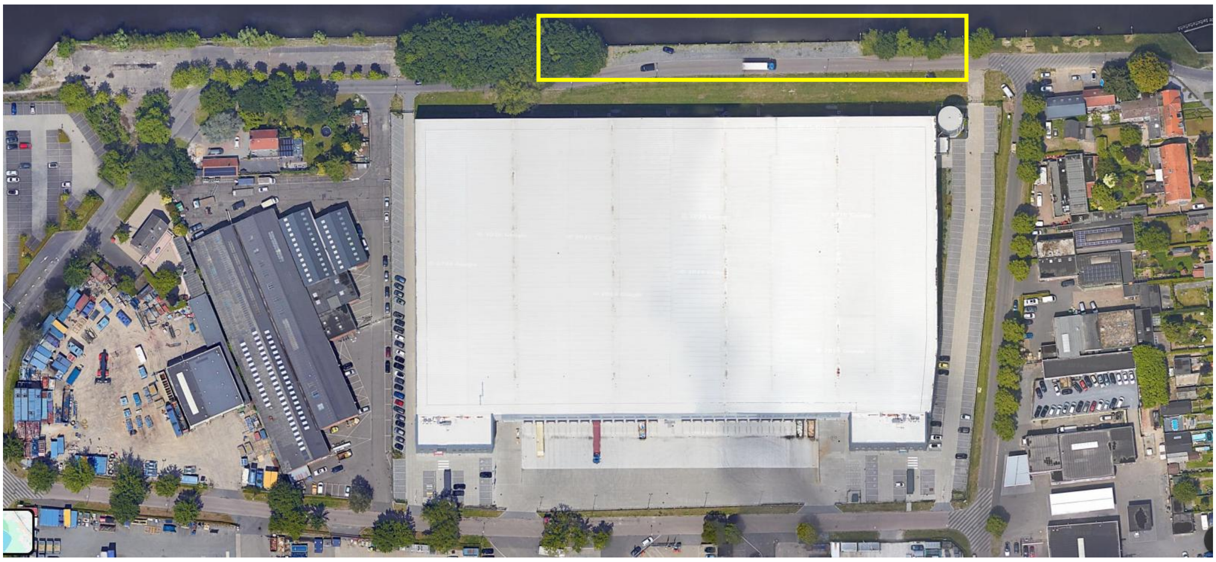

Figure 5-88 Top: Satellite photograph of the Ubiquity site (yellow indicates a potential transhipment quay)
Maps data: © Google

Second, adjacent to the larger Rhenus site, another potential TPT location can be spotted and presents several characteristics comparable to the previously discussed Ubiquity-adjacent quay. The total quay length in this area is approximately 600 metres, the majority of which is currently overgrown with vegetation. Notably, a section of the quay extends further into the waterway, suggesting the historical presence of a dedicated quay or terminal facility at this location. A review of historical satellite imagery dating back to 2005 indicates that the broader area was previously engaged in waterborne transshipment activities, possibly related to cement or construction materials (although this interpretation remains speculative) from the eastern-most part of the quayside (see Figure 5-89). Importantly, the approximately 100-metre section of quay that protrudes into the waterway appears to have remained unused for at least two decades, implying potential degradation but also indicating that it has

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not been obstructed by later redevelopment. If its structural integrity proves adequate, this section could serve as a compact TPT deployment area of roughly 250 square metres, sufficient to accommodate transshipment operations as well as a limited buffer of container units to minimise operational downtime.

Further east, historical imagery from 2005 (see Figure 5-89 bottom) shows a bulk terminal (again, presumably cement-related), where the quay remains largely intact today, although it is currently separated from the main Rhenus premises by fencing (see Figure 5-89). This separation appears to be easily resolved by removing or relocating the fence, thereby reintegrating the quay into the Rhenus site. This eastern quay section measures approximately 130–140 metres in length and 8–10 metres in width, offering ample space to berth multiple 55-metre AUTOFLEX vessels while also providing sufficient quayside area for container handling and buffer storage. Unlike the Ubiquity-adjacent site, there is no public road separating the Rhenus premises from the quay, and while a pedestrian path is visible along the waterfront, the predominantly industrial character of the area suggests limited recreational use. As such, formal integration of the quay into the Rhenus site would likely be feasible, allowing it to be enclosed within the existing perimeter and operated under access-controlled conditions consistent with ISPS-equivalent security standards (even though these are not required for inland terminals). Overall, while some redevelopment would be necessary (most effectively by reincorporating the former bulk terminal area into the Rhenus premises), the site offers significant potential for a TPT deployment that could integrate directly into Rhenus's established and extensive logistics network.

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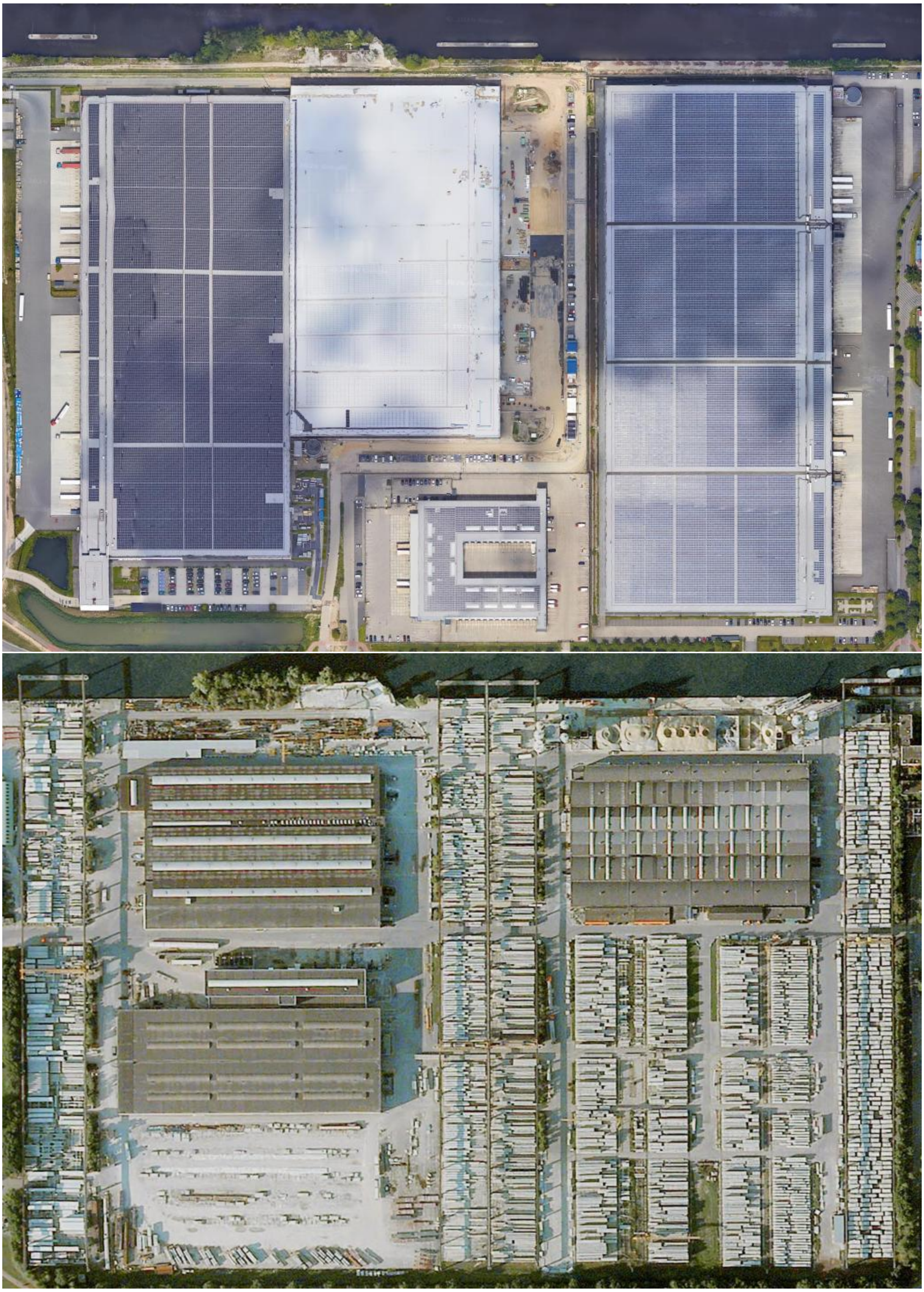

Figure 5-89 Top: The Rhenus location (and potential TPT) in 2025 | Bottom: The same location in 2005.

Maps data: © 2022 Google (top) | © 2005 Google and © 2005 Aerodata International Surveys (bottom)

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5.3.7.2. EINDHOVEN AREA 2: BEST INDUSTRIAL PARK

The second TPT opportunity area in Eindhoven can be found in the industrial area of *Best* a little north of Eindhoven and includes a potential TPT deployment site on a seemingly public piece of quayside infrastructure that is currently used as a car park (see Figure 5-90). The quay measures approximately 145 metres in length and appears to be in generally good condition, with only limited vegetation present at the immediate water edge. The total surface area is around 2.800 square metres, which would be more than sufficient to accommodate transshipment operations as well as a quayside storage buffer to minimise operational downtime. The area is fenced (see Google Street View here), albeit with relatively light fencing, and access is neither monitored nor actively controlled, which means that it may be difficult to be fully compliant with ISPS-equivalent safety metrics. Nevertheless, such fencing would be able to keep citizens and other non-relevant third parties from accidentally accessing the site, which is an important safety aspect as one would want to avoid having pedestrians and similar intermingle within the terminal area whenever containers are being hoisted or freight vehicles (e. g., a truck and/or a tug master) is moving around. An important spatial characteristic of this location is that the quay is set slightly back from the main waterway, meaning that vessels moored for loading or unloading would not obstruct through-traffic on the waterway itself, thereby reducing the risk of congestion caused by TPT operations.

The surrounding area is characterised by a mix of predominantly B2C-oriented businesses, including retailers such as Hornbach (home improvement store), Decathlon (sporting goods store), Houtimport Best (lumber store), and Van Loon (food store), etc., alongside several aluminium and cement wholesalers. Individually, none of these actors are likely to generate sufficient volumes to fill an AUTOFLEX vessel, implying that any TPT deployment at this site would necessarily rely on cargo consolidation and distribution across multiple users. This is further reinforced by the limited on-site storage capacity available at the quay itself, which precludes prolonged container dwell times. As a result, the TPT would need to operate as part of a distributed ecosystem in which nearby businesses use their own premises as extended storage areas, supported by frequent shunts between these sites and the quay. If such coordination and supply chain integration can be achieved, the location could function as a shared TPT serving a diverse group of actors that may not previously have collaborated on logistics. This case thus highlights an additional dimension of the TPT concept: the distinction between terminals that are directly integrated into the premises of a single dominant industrial actor and primarily serve that actor's transport flows, and terminals that are established on neutral or public spaces to provide shared services to a heterogeneous group of industrial actors that may all be interested in transporting cargoes by the waterways, but whom (a) do not have direct access to the water themselves, or (b) do not have enough transport volumes to fill an entire vessel themselves. In the latter configuration, as exemplified by this Eindhoven site, additional consideration must also be given to the management, storage, and redeployment of TPT equipment during periods when the terminal is not in active use. For instance, should the TPT concept make use of a reach stacker for transshipment purposes and a tug master for shunting purposes, and the TPT operational scale is such that it is visited by an AUTOFLEX vessel once or twice per week, what will then practically happen to said reach stacker and tug master on the remaining five to six days of the week? Would it be left on the TPT premises as-is, or would it be stored in a nearby facility

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– and in which? These more practically oriented questions would need to be addressed in the shared TPT model.

Figure 5-90 Top: Industrial area of Best (yellow indicated potential TPT location) | Bottom: Potential TPT location (satellite image)
Maps data: © 2022 Google

5.3.7.3. EINDHOVEN AREA 3: EINDHOVEN AIRPORT

The third industrial area of Eindhoven is situated directly right next to the Eindhoven Airport and, in terms of actor composition and logistics profile, is broadly comparable to the industrial cluster surrounding Schiphol discussed in MSOA2 (section 5.3.2). As in the Schiphol area, the concentration of logistics and industrial activities might suggest potential for modal shift toward inland waterways. However, the physical interface with the waterway presents a significant constraint. While the waterways near Schiphol are characterised by residential development and potential difficulties with public roads alongside the banks, the waterways adjacent to Eindhoven Airport are instead marked by extensive vegetation and the absence of any visible hard, stable quay infrastructure suitable for transshipment. As a result, despite

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the presence of numerous industrial actors that could theoretically benefit from a modal shift to IWT, there is little immediate reasoning to deploy a waterway transhipment concept in this area without substantial waterfront redevelopment. Moreover, given that airport-adjacent logistics often involve time-sensitive, high-value cargo traditionally associated with air freight, any shift toward IWT would potentially face additional challenges related to lead times requirements. Consequently, this area represents a case where latent logistics demand may exist, but where the lack of accessible and serviceable waterfront infrastructure forms a decisive barrier to near-term TPT deployment.

Figure 5-91 Industrial area surrounding Eindhoven Airport
Maps data: © 2022 Google

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5.3.7.4. EINDHOVEN AREA 4: CENTRE

Eindhoven location 4 is located close to the city centre of Eindhoven.

Figure 5-92: Industrial area in the “centre” of Eindhoven
Maps data: © 2022 Google | © 2022 Airbus

Within Eindhoven, a large industrial area is located directly alongside the A2 motorway (left side in Figure 5-92) – a highway widely regarded as the busiest in the Netherlands, running from Amsterdam in the north through Eindhoven to Maastricht in the south and onward into Belgium. The Amsterdam–Eindhoven stretch of this highway has been identified earlier in this research as TIC2. The industrial area in the “centre” of Eindhoven hosts several logistics-relevant actors, most notably multiple divisions of the VDL Group, including the VDL Agrotech Logistics Centre positioned immediately adjacent to the highway (identifiable by its large, black roof in the bottom left corner of Figure 5-92), alongside a broad mix of B2C-oriented businesses and retail stores.

Along the waterfront, two potential infrastructures for TPT deployment can be identified. The first is an abandoned quay located opposite the MIREC recycling facility (marked as red #1 on Figure 5-92), while the second is an active bulk-handling waterfront shared by the concrete producers Mebin and Weber Beamix (Saint-Gobain) and the animal feed manufacturer ABZ Diervoeding (marked as red #2 on Figure 5-92). At the eastern end of this latter quay, HKS Metal is also present, although no clear evidence of waterborne transshipment activities linked to their premises can currently be observed.

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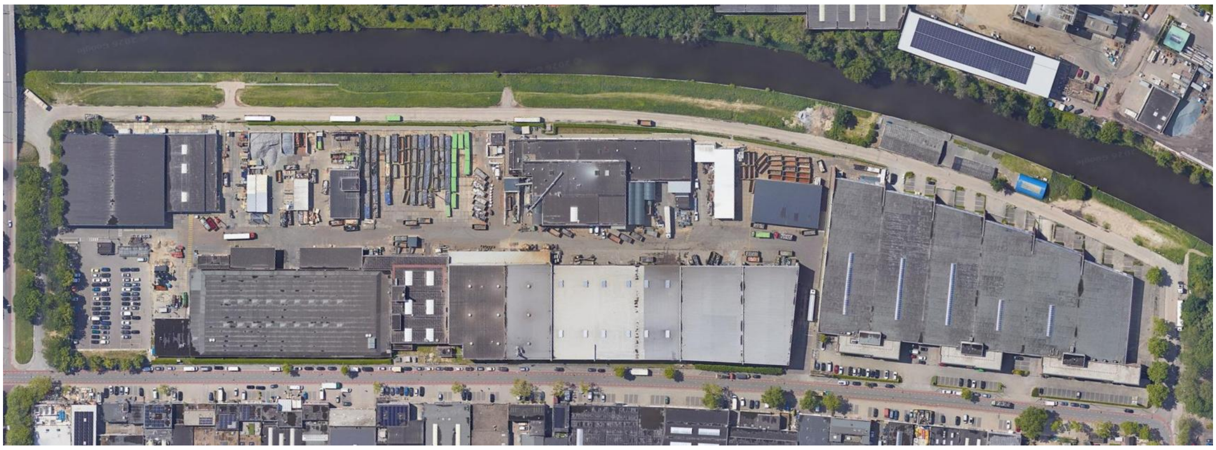

Figure 5-93 First potential TPT location within the industrial area in the “centre” of Eindhoven

Maps data: © 2022 Google

Focusing on the first of these sites (see Figure 5-93), the quay extends approximately 450 m in its eastern section and around 80 m in its western section, with these two stretches separated by a small building housing the Eindhoven Kayak Club. The available terminal width is approximately 17 m, which should be sufficient to accommodate both transshipment operations and a modest storage buffer, provided throughput volumes remain moderate. The site appears largely unused, unfenced, and in relatively good physical condition, with only limited grass vegetation that would require removal and paving. Historical satellite imagery suggests that the area has never been formally developed, yet it seems to have been consistently maintained to prevent excessive overgrowth. Notably, however, this general rule comes with an exception: satellite imagery from 2013 indicates that the site indeed has been used, temporarily, as a transshipment for some type of general cargo transport over the inland waterways (i.e. neither bulk nor containerised cargo). This has potentially been directly connected to some of MIREC’s operations, although this remains entirely speculative on behalf of the authors. From the next available satellite imagery in 2016, these activities have ceased entirely for reasons also unknown to the authors. This historical develop, based on satellite images from 2012, 2013 and 2016, can be seen in Figure 5-94.

Nonetheless, this historical use provides a solid indication that the site is not only theoretically but also practically capable of supporting transshipment operations and freight movements via the inland waterways. The observed use of the quay for general cargo handling suggests that the basic infrastructural characteristics required for waterside operations (such as quay accessibility, mooring facilities etc.) have previously been sufficient and may still be so today (subject to verification of structural integrity). This strengthens the argument that the location is technically suitable for renewed transshipment activities and that a TPT concept could realistically reactivate the site. At the same time, the lack of fencing, monitoring, or controlled access introduces considerations related to safety, liability, and cargo security from third party access to the premises. Any TPT deployment would therefore need to incorporate organisational and/or physical measures to manage these risks, such as temporary oversight and/or selective fencing. The site could be developed as a shared TPT servicing multiple firms across the industrial area through consolidation and coordination mechanisms, or it could be more tightly integrated into MIREC’s operations, effectively reinstating a dedicated waterside interface that reflects the site’s apparent historical function.

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Figure 5-94 The potential transshipment location in front of the MIREC recycling centre in 2012 (top), 2013 (middle) and 2016 (bottom).

Maps data: © 2012 Google and © 2012 Maxar Technologies (top) | © 2013 Google and © 2013 Maxar Technologies (middle) | © 2016 Google and © 2016 Maxar Technologies (top)

The second potential TPT location within the central industrial area of Eindhoven is located along a shared waterfront used by the cement producers Mebin and Weber Beamix, the animal feed manufacturer ABZ Diervoeding, and the recycling centre HKS Metals. The site is visible in detail in Figure 5-95. While the HKS Metals premises are clearly identifiable in satellite and street-level imagery, the spatial separation between Mebin, Weber Beamix, and

ABZ is less clearly delineated. The quay has a total length of almost 400 metres. The easternmost approximately 200 metres of the quay (left in Figure 5-95), located opposite the HKS Metals site, appears largely unused for active transshipment, although satellite imagery shows that commercial inland vessels are occasionally moored there. This suggests that basic mooring infrastructure is present and that the quay could readily be activated for transshipment purposes. Moving westward (to the right in Figure 5-95), roughly the next 100 metres of quay are actively used by ABZ as a bulk terminal for inland waterway transport of animal feed. As can be seen in the middle of Figure 5-95, the animal feed is conveyed from the main production facility via a pipe to a quayside storage compartment, from which a fixed digger (see Google Street View here) loads the cargo directly onto vessels (and, presumably, vice versa). While this section operates just fine as it is, it also demonstrates the relatively low-complexity equipment setup with which effective transshipment can be achieved. Said differently, this highlights the potential suitability for low-resolution TPT deployments at this site in particular and all sites in general. The westernmost approximately 100 metres of quay (right in Figure 5-95) are used by Mebin and/or Weber Beamix and resemble the many cement bulk terminals analysed earlier in this study: a mobile crane, apparently rail-mounted, operates between the waterway and a series of cement storage compartments, moving parallel to the quay along the operational area. In contrast to the fixed ABZ digger, this equipment is clearly mobile along the quay.

Figure 5-95 Second potential TPT location within the industrial area in the "centre" of Eindhoven
Maps Data: © 2022 Google

Based on these characteristics, three potential TPT configurations can be identified at this site. First, a dedicated container transshipment area could be developed along the easternmost 100 metres of the quay (left in Figure 5-95), independent of the existing bulk operations and directly opposite HKS Metals. Second, a hybrid container–bulk transshipment solution could be established by utilising the fixed ABZ digger during periods when it is not required for feed shipments, thereby leveraging already-installed equipment; containers could be temporarily stored either on the quay section between the ABZ digger and the HKS Metals frontage (where an inland vessel is currently moored in Figure 5-95) or potentially on a floating platform at the same location. Alternatively, containers could also be stored at the area within the ABZ premises where three shipping containers can be seen in Figure 5-95. Third, a similar hybrid solution could be developed using the mobile crane at the Mebin/Weber Beamix section, with containers stored to the west of the cement compartments in a smaller paved area of approximately 500 m² (right in Figure 5-95). This is however subject to agreement with

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local authorities given its probably status as a public area. The latter two configurations introduce an additional dimension to the modular TPT concept: the distinction between fixed and mobile shore-side cargo handling equipment. The relative advantages of each type are highly context-dependent, varying with geographical, operational, and commercial conditions, but together they underscore the adaptability of the TPT concept when embedded within heterogeneous, multi-user industrial waterfronts.

The site seems to be fenced already, which would allow the TPT concept to prevent unwanted or uninvited third parties into the premises, thus ensuring the safety and security of both persons, equipment and the transported cargoes. However, given the uncertain plot borders between the actors at the site, particular between ABZ, Mebin and Weber Beamix, further investigation into how to do this effectively should be undertaken. Furthermore, it is necessary to investigate how the three entities potentially could collaborate on a TPT concept that uses common space as a storage buffer such that transhipment can be undertaken seamlessly without significant latency or delays, and so that, potentially, multiple AUTOFLEX vessels can be serviced simultaneously. A hybrid solution that combines existing and additional transhipment equipment may be wanted to improve efficiency and minimize the TPT's impact on existing operations at the site.

In addition to the waterfront sites identified earlier and the potential TPT locations, a couple of adjacent and significant industrial areas without direct access to inland waterways may nonetheless be relevant to the proposed TPT locations due to their scale and concentration of potential transport demand. These non-water-facing sites could plausibly function as hinterland customers of one or more TPTs within the Eindhoven area. To the east of Eindhoven (marked as "blue A" in Figure 5-96), a large DAF Trucks manufacturing plant is located, which could theoretically make use of TPT site in location 4 (or any of the other location to be fair). Of even greater relevance is the logistics cluster situated to the northwest on the outskirts of Eindhoven (marked "blue B" in Figure 5-96), where a dense concentration of major logistics service providers can be found, including DHL, GXO, DSV, and FedEx, alongside the Rail Terminal Eindhoven, operated by Van Rooijen Logistics, which offers long-distance rail freight connections to and from the region. This co-location of road and rail and logistics activities suggests that while modal shift services (to rail) is already available to the logistics actors at this site, it may also provide a potentially strong basis for further intermodal integration with IWT via a TPT from either of the four Eindhoven areas, although probably area 1 is more appealing given that area 3 has no transhipment sites, area 2 has only a smaller transhipment site and that diverging trucks into the centre of Eindhoven would have a reverse effect on congestion and consequent external costs. Thus, if this logistics cluster were to become a primary source of demand for inland shipping, it would arguably be more strategic to prioritise the TPT opportunities in area 1.

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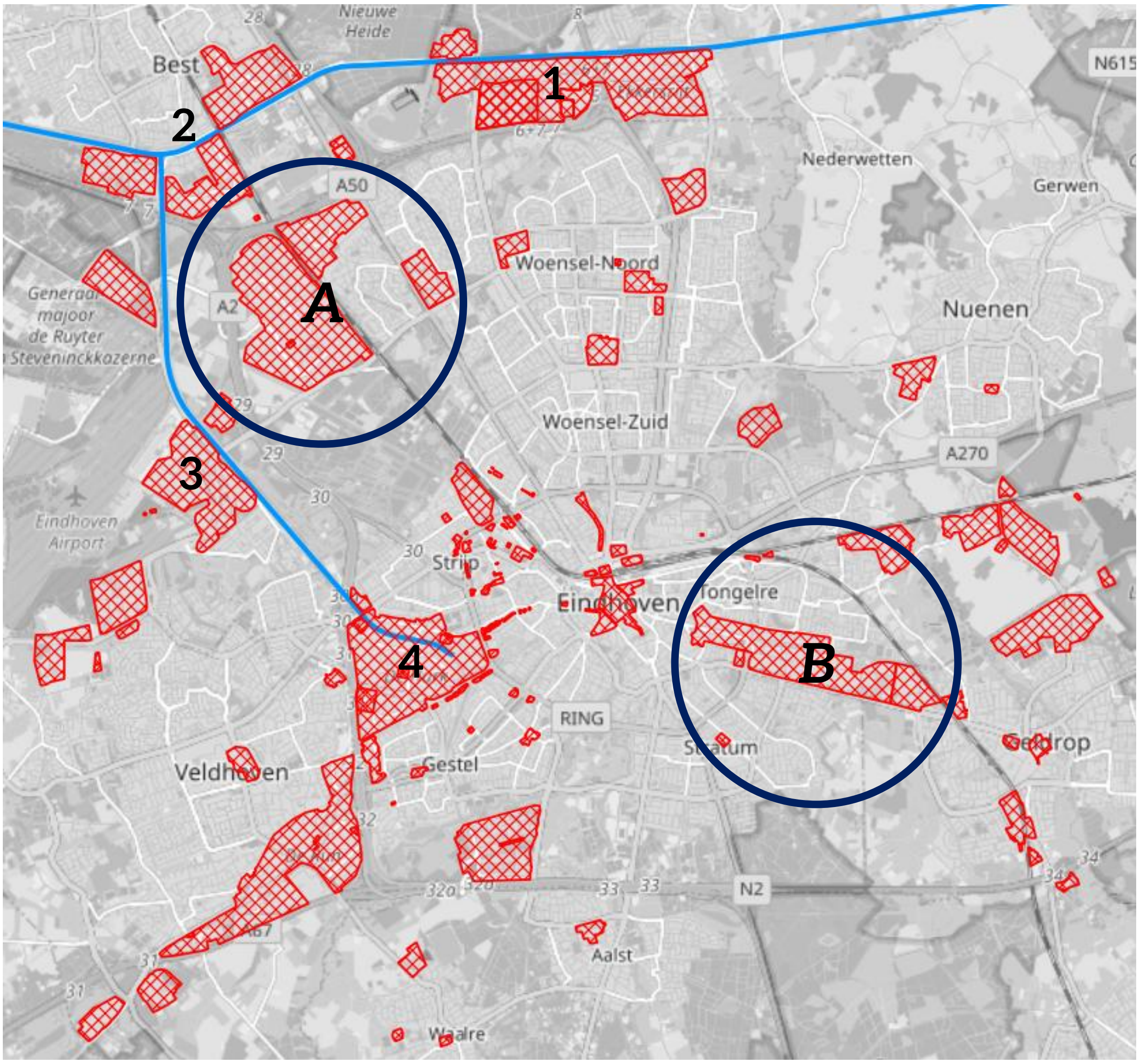

Figure 5-96: The four TPT opportunity areas (yellow) and other MSCs not immediately adjacent to the waterways (blue)
Maps Data: OpenStreetMap, EuRIS

5.4 THE TEMPORARY PORT TERMINAL (TPT) CONCEPT

From the extensive assessment of sites in Haarlem, Schiphol, Leiden, Den Haag, Delft, Roosendaal, Breda, and Eindhoven, several repeating patterns emerge. These patterns reveal what tends to work, what tends to be missing, and what tends to repeatedly determine the viability of using a site for transshipment purposes. These common denominators identified across the sites in section 5.3 will become the backbone for extracting design requirements for the TPT concept.

5.4.1. THE DESIGN REQUIREMENTS OF THE TPT CONCEPT

The analysis reveals a set of recurring physical, operational, and contextual “denominators”, i.e. shared traits that consistently shape the feasibility of a potential TPT concept across the analysed sites. These denominators concern not only the technical usability of quays and

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their immediate working areas, but also how surrounding land uses, access arrangements, site governance, and existing industrial practices influence what forms of transshipment are realistically achievable. Consequently, these denominators will be used as actionable design requirements for the TPT development, as they must be accounted for in some shape or form within the concept itself. The following subsections synthesise these cross-site denominators and outline the implications they hold for the TPT concept development.

5.4.1.1. QUAY INTEGRITY AND MOORING READINESS

Across the analysed sites, quay integrity and mooring readiness consistently determine whether a location is feasible to call with the AUTOFLEX vessel. Some waterfronts are evidently maintained and currently in use, while others have partial overgrowth at the waterline and uncertain structural condition of quay walls. Some quays are short, irregular or do not appear to have mooring fixtures (such as bollards and/or piles). Some quays indicate that they have been in use recently, while others remain ambiguous as to whether they have ever been developed for that purpose. In sum, the analysis repeatedly notes that the mere presence of a quay does not necessarily equate that the TPT concept is operationally viable or feasible at the site.

For the TPT concept, quay integrity and mooring readiness act as a basic feasibility requirement and influence the design of the entire setup. If safe, predictable mooring cannot be ensured, then cargo handling and storage planning become somewhat meaningless. Short usable lengths, poor mooring opportunities or severe vegetation along the waterfront increase call time due to extra repositioning and restricted access. They also raise safety and liability risks, especially where the public is close to the waterfront, because unclear edges and improvised mooring points worsen exposure during heavy lifts. Quay condition also shapes which operational options are actually possible, e. g. whether the surface can support cargo handling equipment, and also affects how quickly a site can be activated. Sites with solid edges and visible, usable fixtures can be brought "online" far faster than those with missing hardware, overgrowth, or signs of wear.

5.4.1.2. WATERFRONT ACCESSIBILITY FOR VESSEL OPERATIONS

The analysis shows that even where a quay is structurally sound and theoretically long enough to accommodate the AUTOFLEX vessel, it is not always possible to access the vessel along its full working length. Thus, waterfront accessibility, i.e. the capability to access the vessel moored alongside the quay, becomes an important design parameter. Across the sites, three issues repeatedly influence this access. First, vegetation at the waterline often blocks or hides the vessel side, especially at quays that have not been used recently. Thus, vegetation is not only a matter of quay integrity and mooring readiness, but also of waterfront accessibility from shoreside. Second, some quay fronts are very narrow. This limits not only the mooring capability of the site, as mentioned, but also how close shore-based cargo handling equipment can get to the vessel and how much of the vessel's cargo bays can be reached by this equipment. Said differently, even if the AUTOFLEX vessel would be able to moor at the site, this does not necessarily entail that transhipment operations would be possible also. In some places the quay width is only a few metres, which significantly reduce access to the vessel. Third, physical obstacles placed directly at the quay, such as storage compartments, buildings etc., break up the working area, which means that although a vessel might be able to berth at the site and that the integrity of the waterfront is good, it might not be worked efficiently due to waterfront access limitations. Together, these points show that the feasibility of a TPT concept is not only about quay integrity and mooring readiness, but also about whether the

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moored vessel's cargo can be reached safely and continuously, without needing to reposition the vessel excessively throughout the transhipment operations.

For the TPT concept, limited waterfront access affects both feasibility and the choice of handling methods. Vegetation and obstacles at the waterfront create uncertainty in cycle times because reaching all the cargo may require moving the vessel or removing on-shore obstacles. Narrow or partially accessible sections may force operations to be concentrated in one area or restrict the angle with which the cargo handling equipment approach the vessel. Because TPT sites rely on bringing equipment in temporarily, these constraints directly affect which operational setups are possible and how reliable they are. As with quay integrity, waterfront accessibility must be assessed early, because it determines how to berth the vessel, if at all, but also how the cargo of the vessel can be practically accessed for transhipment purposes, if at all.

5.4.1.3. OPERATIONAL APRON FOR CARGO HANDLING EQUIPMENT

The analysis repeatedly shows variation in the operational *apron* of the various sites. For the purposes of this report, the term *apron* refers to the working area on the quay where cargo is handled and where equipment and vehicles move. In some places, this area is wide, paved, and free of obstacles. In others, it is narrow, segmented, or blocked by obstacles ashore, such as buildings, storage compartments and/or other structures. However, the analysis also shows examples where cargo is handled with very little apron space, or where the main working area is actually on the water while the shore is used only for minimal staging. Overall, apron width, layout, and "cleanliness" strongly influence how and where cargo can be handled, and how fast operations can run.

For the TPT concept, apron conditions set clear design requirements. Narrow or segmented aprons make it harder for equipment to turn or approach the vessel, which slows down handling and concentrates transhipment activity into smaller sections of the quay. Wide and clear aprons allow for smoother operations without excessive reconfiguration of the site (e. g., moving parking areas, storage units etc.). In short, apron characteristics determine which handling setups are possible at each site, whether the vessel can be worked continuously along its length, and how predictable cycle times will be. The TPT model must account for these factors when defining feasible operating modes and planning assumptions.

5.4.1.4. STORAGE MODALITIES FOR CARGO BUFFERING

The analysis shows that storage options on or immediately next to the quay vary widely across the sites, and this strongly affects how cargo can be managed. Some sites have on-land storage on or right next to the quay, ranging from large, paved yards to smaller hardstanding areas such as car parks or similar. Other sites have little to no usable storage by the quay because it is simply too narrow or blocked by buildings, compartments, or general clutter. A common pattern across many sites is the use of floating storage, where barges or pontoons are moored at the site and (potentially) used as extra storage or as extensions of the terminal into the waterway. Some sites are also laid out to (potentially) rely on off-site or distributed storage, such as nearby container depots or plots a short drive away from the quay. Overall, a mix of (potential) on-land, floating, and off-site storage solutions is common along the corridor.

For the TPT concept, these differences mean handling plans must adapt to very different storage setups. When storage is available at the quay, cargo can be buffered easily, reducing pressure on just-in-time (JIT) transport management between the quay area, the storage area and third-parties dropping-off/picking-up cargo. When quayside space is small or blocked,

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operations need tight coordination because cargo must move directly between vessel and truck with little room for buffering. Where (potential) floating storage is used, it can help compensate for limited land space, but it also requires attention to safe and seamless cargo access for loading/unloading to/from the vessel. Where (potential) off-site storage is used, operations depend on well-coordinated shunts between the quay and the nearby storage areas. All these conditions, i.e. where the storage area is not immediately available at the quay, are extra steps that may affect operational viability and commercial feasibility of the concept. In short, storage conditions vary greatly, and a TPT model cannot assume that quayside storage will always be available or sufficient. Thus, the concept must stay flexible enough to work with very different storage profiles.

5.4.1.5. UTILITIES AT THE WATERFRONT

The analysis shows that basic utilities at the waterfront vary widely between sites. In this regard, utilities primarily refer to the availability of light and power. These utilities cannot be assumed to be present even when the quay itself looks intact, as many quays appear simply to be hard edges with no supporting infrastructure. Active industrial sites usually have more utilities, but these may be designated exclusively for their own modus operandi and not for general cargo work. Overall, technical readiness ranges from fully serviced industrial waterfronts to very basic quays that would need extra support to function as working areas.

For the TPT concept, this posits another design requirement or concept parameter with important operational consequences. Sites without proper lighting or power availability are limited in when and how cargo can be handled, meaning operations must match the utilities or conditions that already exist at the site. On the other hand, sites with built-in industrial utilities may still be problematic as these utilities may be designated or even designed for non-compatible operations today. Furthermore, zoning requirements may put further restrictions on when light and power sources may be used, meaning that even if the utilities are permanently available, they may not be used continuously. In all cases, these conditions show that the TPT concept must be able to work both in low- and high-utility environments and be attentive to each site's physical and political limits.

5.4.1.6. PUBLIC INTERFACE AND URBAN COMPATIBILITY

The analysis shows that many possible waterfront sites are located in busy urban or semi-urban areas. Roads, bicycle paths, and footpaths often run directly next to the waterfront, sometimes with only a very narrow pavement or no separation at all between the public area and the (potential) quay working area. In these places, pedestrians, cyclists, and cars pass within a few metres of where cargo operations would take place. Some quays are close to or right next to homes or leisure areas, where noise, light-pollution, and industrial activity may be sensitive issues. The analysis also identifies sites where old industrial areas are being turned into residential or recreational areas (or both), meaning freight activity may no longer be compatible in the future. Overall, many potential TPT locations sit in environments where terminal operations must in some shape or form interface with the public and citizens.

For the TPT concept, this creates important operational and societal challenges. Where public roads or paths run directly along the water, the TPT introduces potential contact points and coordination between heavy cargo handling equipment and by-passers. This increases the need for clear separation, good visibility, and predictable equipment movements, for example. In residential areas, noise and lighting may restrict when operations can occur, creating not

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just physical but also temporal constraints to the TPT concept. Thus, even if a quay is technically suitable and the waterfront, storage and utility aspects are all fit-for-purpose, compatibility with nearby public uses will strongly shape the scale and timing of operations. Thus, the TPT is not only a technical setup: its feasibility also depends on whether cargo operations can safely and acceptably fit into the environment surrounding the candidate site.

5.4.1.7. ACCESS CONTROL AND SECURITY

The analysis shows substantial variation in how sites manage (or could manage) access and security. Some active industrial sites, such as logistics centres, bulk terminals etc., have clear perimeters with fences, gates, and controlled entry points. These places already separate internal traffic from the public and have predictable access and formalised security routines. Many other sites have no real perimeter at all. However, in mixed-use or semi-urban areas where the waterfront serves recreation, housing, or commercial activity rather than freight, the quay often opens directly onto public roads, bicycle paths and/or promenades. Brownfields and partly used industrial plots fall somewhere in between, with partly-fenced and -controlled perimeters. Across the sites, the line between public space and operational space is sometimes unclear or completely missing, while other times it is well-established within existing industrial sites with well-controlled access points.

For the TPT concept, these differences matter. Sites where fences and gates are established can be easier to integrate into existing routines, but operations will need to follow the site's rules, traffic patterns and overall operational "rhythm". Sites where the quay is fully open to the public will have major concerns of safety and security, especially during transhipment operations, and this may limit when or how cargo can be handled. Partially fenced sites require careful planning to mark operational areas clearly, since unclear boundaries increase the risk of the public entering the work zone by accident. This is particularly important when all or some of the equipment used for transport, such as the AUTOFLEX vessel, is unmanned and/or autonomous. Overall, access control is not a secondary issue. It directly shapes operating hours, cargo handling safety and the level of supervision needed to manage interactions between terminal operations and the surrounding public environment.

5.4.1.8. HINTERLAND CONNECTIVITY

The analysis shows that last-mile access depends on how easily trucks can reach, move around, and leave the waterfront. Some sites sit behind narrow public roads or streets not designed for heavy trucks, which creates tight turns, limited space for reversing, and conflicts with normal traffic. Other sites have internal roads designed for the current business operations, not for transshipment purposes. Many quays are also broken into small usable sections by fixed structures or clutter, reducing the number of places where trucks can safely approach the vessel. Where storage is off-site, trucks must be able to pick-up and drop-off cargo at these sites, and terminal-dedicated vehicles must be able to shuttle cargo between the storage area(s) and the quay. These short trips may require crossing public roads or navigating narrow industrial streets, which adds time and unpredictability. Overall, hinterland "connectivity" is not just about having a road nearby: it is an intricate matter of coordinating where and when to drop things off and pick things up such that the overall transport efforts remain operationally and commercially viable.

For the TPT model, these conditions have direct operational effects. When quays have tight access points (sharp corners, narrow roads etc.), truck movements are slowed down which reduces how many trucks can be processed both at once and over a given period. This in turn

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makes schedules more fragile. If the site lacks a clear internal loop or proper staging space near the quay, congestion can build up quickly, especially where apron space is already limited. Mixing truck routes with public traffic can also create additional congestion and potentially force work into off-peak time windows (e. g., at night or in the weekends) for safety reasons. If the site depends on remote storage, very small delays in the shuttle trips can extend vessel dwell time significantly and compromise overall transport performance. In summary, hinterland connectivity sets the practical limits for how first- and last-mile vehicles, such as trucks, can be sequenced, staged, and “flipped” at the site with minimal impact on the transhipment operations and overall transport performance. It also shapes how well the TPT concept can keep vessel operations independent from truck operations and local traffic conditions.

5.4.1.9. SITE-USE MODEL FOR ANCHOR TENANT OR SHARED OPERATIONS

The analysis shows two main types of sites: anchor-tenant sites and shared-use sites. Anchor tenant sites are built around one main user, i.e. the *anchor tenant* such as a factory, a distribution centre, or a bulk terminal etc. These sites usually have clear fences, controlled access, and internal roads designed for that single operation and their waterfronts often include equipment or layouts built specifically for that user. In contrast, shared-use sites appear where public or semi-public quays can serve multiple users or where one or more smaller businesses may have waterfront accessibility but not enough scope in their operations to erect a fully-fledged transhipment terminal on their own. Here, storage and staging areas are spread across different premises, and the quay mainly acts as a shared loading and unloading point rather than a full terminal area. Both types of sites appear frequently in the analysis.

For the TPT concept, each model creates different operational conditions. At anchor-tenant sites, operations are usually more predictable because one actor controls the flow of cargo and the operations at the site. However, transshipment must fit with the tenant’s main activities, and their infrastructure may not suit containerised cargo handling as proposed in the AUTOFLEX transport system. At shared-use sites, the quay can serve several shippers and help combine demand, but coordination becomes more complex. Storage is spread out into an industrial ecosystem, short shuttles between quay and storage areas increase, and arrivals (both of vessels and of trucks) are driven by several independent schedules. This can improve utilisation but also increases risks of congestion and competition for staging space or access to the quay. Overall, the TPT model must account for these differences. Site governance, operating windows, and control of nearby land all affect how fast and reliably cargo can be handled.

5.4.1.10. LIFECYCLE STATUS OF WATERFRONT SITES

The analysis identifies different types of waterfront sites, based around their current and potential usability and, particularly, how quickly these sites could be used for transhipment purposes. First, *active transshipment sites* are found, which are working freight sites, usually for bulk cargoes like sand, cement, or waste. They show clear signs of existing use, such as handling equipment, vessels, and mooring fixtures. Second, *Active non-transshipment sites* are found, which are locations that host active businesses (e. g., factories, distribution centres, utilities) but without the quay being used for transhipment purposes today. The waterfront often shows overgrowth, parked vehicles, or informal uses along the edge. Third, *brownfields or partly abandoned sites* are found, which are sites where the quay structure is still present, but is overgrown, possibly unstable, and often has unclear ownership or management

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structures. Furthermore, the analysis also showed that sites can shift between these states over time. Some old industrial quays have been partly removed or repurposed for residential use, whereas in other areas, an active bulk berth may sit right next to an unused brownfield. This produces a patchwork of conditions even within the same area.

For the TPT concept, these lifecycle states matter directly in how the TPT should be outfitted. *Active transshipment sites* can usually be activated quickly and offer predictable working conditions, but their layouts and schedules are built around existing usage which needs to be accounted for in the operational blueprint of the TPT. *Active non-transshipment* sites may provide good infrastructure and access, but the quay may need inspection in order to ensure its integrity and careful coordination must be done with neighbouring actors to avoid conflicts with ongoing operations. *Brownfields and abandoned sites* may be attractive because they offer an open, unused space, but they come with uncertainty around structural integrity, governance structures and general availability (especially if redevelopment is planned). Overall, lifecycle status should be treated as a key planning factor in the design requirements of the TPT. It signals how fast a site can be activated, how complex coordination will be, what operating windows are realistically available, and how stable the site's freight role will be over time.

5.4.1.11. TEMPORAL AVAILABILITY OF THE SITE

The analysis shows that candidate waterfronts differ in when they can realistically host freight activity. Many active industrial premises operate intensively during weekday daytime, leaving periods at night or in weekends when the waterfront is comparatively unoccupied. In other locations, especially where public roads/paths or residential areas sit directly at the waterfront, freight activity may be limited at daytime because of traffic conflicts and at nighttime because of noise and light pollution. Across the analysis, sites are found to be operational either all day, only in off-hours, or only within narrow, defined periods.

For the TPT concept, temporal availability is an important design requirement. If a site is only available outside normal business hours, e. g., at nighttime, operations must fit into a shorter time window which requires tighter coordination with internal equipment and external vehicles. At sites close to the public or sensitive neighbours, factors like lighting, traffic peaks, and noise limits restrict when cargo can be handled and staged. Even sites available all day may experience predictable slowdowns at certain times, such as during shift changes, gate peaks, or internal traffic conflicts. Overall, temporal availability shapes achievable service frequency, expected vessel dwell times, and how well vessel operations can be separated from local traffic patterns. It must be treated as a core planning parameter for any TPT deployment.

5.4.1.12. RETROFITTING AND REUSE OF EXISTING TRANSSHIPMENT EQUIPMENT

The analysis shows that many waterfronts already have handling equipment, but most of it is designed for bulk cargo and not containers. Common examples include quay-side diggers, rail-mounted bulk cranes, and other machinery used at cement, sand, waste, or construction-material terminals. At many sites, this equipment is busy during core opening hours but sits idle throughout the night and weekends. In other places, nearby industries own cranes or heavy-lift gear that are not used outside that business' opening hours (e. g., cranes used for construction purposes), which could potentially be leased *temporarily* at night and/or on weekends. The analysis also notes cases where handling happens from the water using cranes or diggers on barges, as well as sites where inland vessels act as temporary storage or

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extensions of on-shore processes. Together, these patterns show that underused or part-time equipment is common along the investigated corridors. While not designed for containers, this equipment could potentially be adapted or scheduled for extra tasks when primary users do not need it. This could be a way in which primary users create extra revenue from their equipment and extend its effective operational hours.

For the TPT model, this has important operational implications as to whether supplementary equipment must be provided or whether existing equipment can be repurposed. Being able to use existing bulk-oriented cargo handling equipment for container-based transshipment could be a way not only to develop a more circular transshipment concept by extending the operational scope of the equipment, it may also be a way to make the most of the layout of the site such that existing operational areas could be used for the same purposes. While idle equipment offers opportunities to use existing capacity in off-peak hours, it also creates dependencies on the schedules and rules of the main site users. More broadly, reusing existing equipment affects expected handling speeds, available working windows, security during operations, and how activities must be coordinated with the primary industrial users of that equipment. In short, any TPT setup in these environments must reflect that the equipment on site was not built for container flows and must adapt to the realities of its availability, design, and main operating duties.

5.4.2. THE PRECONDITIONS OF THE TPT CONCEPT

Deploying a TPT is only feasible if a number of fundamental, site-specific conditions are satisfied. These conditions are not “design choices” or “modular configurations” in the sense of the building blocks introduced later. Instead, they represent minimal enabling properties that must be present (or can feasibly be established) before any TPT configuration can be considered. In other words, they define the baseline for whether or not a site is feasible to use for TPT purposes. The distinction between *preconditions* and *building blocks* is important. *Preconditions* are non-negotiable. If a precondition fails (and cannot be feasibly remedied), no variant of the TPT concept can operate at the site. *Building blocks*, by contrast, are configurable solutions that can adapt to the many logistics contexts once the preconditions are met.

These preconditions have been derived from the analysis in section 5.3 , where numerous sites ultimately proved infeasible due to one or more structural constraints, such as:

- Quays where safe mooring was impossible due to missing mooring fixtures, severe overgrowth, or (assumed) edge deterioration;
- Sites where basic operational surfaces were absent or, at best, questionable due to severe overgrowth which would not permit the movement of heavy vehicles;
- Locations where overhead pipes, on-quay storage compartments, or building geometry (etc.) made container transshipment near impossible;
- Places where no continuous route existed between the transhipment site and any feasible storage area or handover location;
- Waterfronts that would soon be redeveloped into housing or commercial real estate, eliminating any viable operational horizon.

Across these cases, it was discovered that if certain foundational conditions are not met, the TPT concept would not be able to function regardless of how the building blocks were configured. This section therefore establishes the preconditions that collectively determine whether a site is applicable for TPT deployment in an “as-is” or “to-be” state.

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To operationalise the assessment of candidate locations, each requirement can be assigned a numerical score reflecting the degree to which the site satisfies that specific precondition. This allows the analytical framework to move beyond purely qualitative judgement and instead express the suitability of a site in a transparent, comparable, and reproducible manner. Each precondition is thus scored on a four-level scale, as follows:

Score	*Definition*
+3	*The precondition is already satisfied.*
+2	*The precondition can be satisfied through minor upgrade.* *A rough "is it worth it?" assessment should be made.*
+1	*The precondition can be satisfied only through major upgrades.* *A thorough "is it worth it?" should be made.*
−∞	*The precondition cannot be satisfied by reasonable means; the site is not applicable for TPT use unless fundamental changes occur.*

By aggregating the scores of each requirement, we can construct a TPT applicability indicator that summarises the overall feasibility level of deploying a Temporary Port Terminal at a given site. Formally, the indicator is defined as the average score across all evaluated requirements:

$$TPT\ Applicability\ Indicator = \frac{1}{N}\sum_{i=1}^{N} Ri$$

where:

Ri denotes the score assigned to requirement i, and

N is the total number of preconditions included in the evaluation

High values indicate strong overall applicability, whereas low values signal that a site would require substantial adaptations (or may not be viable at all) for TPT deployment, with *0* indicating absolute *Not Applicable (N/A)*. Thus, the scoring is not intended to produce a deterministic "yes/no" decision by itself, but serves the three following purposes:

- Assessing showstoppers: Any −∞ scores render the site inapplicable.
- Assessing remedies: *+2* or *+1* scores identify what work is required to activate the site.
- Assessing strategic priorities: High-scoring sites represent low-effort opportunities; low-scoring but salvageable sites require a judgement of whether the investments or stakeholder efforts are justified by potential demand.

The following subsections describe each of the identified preconditions.

5.4.2.1. QUAY SURFACE

The quay surface precondition concerns the physical usability of the immediate working area where cargo-handling equipment must operate. It addresses whether there is a continuous, structurally sound and traversable platform adjacent to the water that can safely carry the weight and manoeuvring forces of the intended equipment. This includes both the structural condition of the quay edge and the general state of the surface—whether it is paved, partly reclaimed by vegetation, obstructed by debris, or interrupted by irregular patches. The analysis repeatedly showed that the mere presence of a quay does not guarantee operational usability: many quays exhibit overgrowth, uncertain load-bearing capacity, or fragmented

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hardstanding that would prevent safe movement of heavy machinery. Thus, this precondition establishes the basic requirement that a TPT needs an existing land-side platform that can serve as the foundation for any transhipment activity.

Score	*Definition*
+3	*The surface is already in working condition – typically paved, structurally intact, and free of obstacles. It requires no more than trivial cleaning*
+2	*The surface is fundamentally sound but needs minor interventions such as brush-cutting or small-scale patching to restore usability.*
+1	*The surface requires major preparation, for example mechanised clearing of dense vegetation, reinforcement through temporary mats, or repairs to sections of the surface.*
−∞	*The surface cannot be made safe within reasonable effort—such as where there is structural instability, severe edge deterioration, or ground contamination that cannot be remediated for temporary use.*

5.4.2.2. QUAY CLEARANCE

The quay clearance precondition concerns the availability of a physically unobstructed lifting and movement envelope along the waterfront. It evaluates whether containers can be safely lifted between vessel and quay without interference from fixed structures such as overhead pipes, canopies, building projections, bulk storage bins, or elevated utilities. In addition to vertical clearance, it also captures horizontal obstructions that break the continuity of the working face, including compartments built directly against the edge or immovable installations that prevent equipment from approaching the hull at the correct angle. Across the analysed sites, it became evident that many otherwise promising waterfronts were compromised not because the quay was unusable, but because key sections were rendered inaccessible due to permanent infrastructure placed flush against the water. As safe container lifting requires predictable arcs and stable approach paths, any fixed obstruction directly affecting the lifting envelope can undermine the feasibility of TPT operations irrespective of other favourable site characteristics.

Score	*Definition*
+3	*The quay is already clear, with no vertical or horizontal conflicts restricting cargo-handling movements*
+2	*The quay clearance is largely acceptable but requires minor interventions, such as relocating smaller structures, vehicles, and/or barriers without altering the fundamental layout*
+1	*The quay clearance requires major physical modifications, such as removing or redesigning sizeable installations like bulk compartments, overhead pipes, or structural protrusions*
−∞	*The quay clearance conflicts are inherently unresolvable within the practical or economic constraints of the TPT concept, such as protected or irremovable overhead infrastructure located directly within the lifting arc*

5.4.2.3. QUAY ACCESS

The quay access precondition concerns the existence of a continuous, safe, and operationally workable route between the transhipment point and the designated handover or storage area. This precondition focuses on physical and functional continuity: equipment and vehicles must be able to move from the quay to the storage or pickup area without encountering hard barriers such as locked yards, walls without gates, fenced-off corridors, or

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internal layouts that prevent movement without trespassing through third-party premises. The analysis showed that many otherwise promising quays were limited by disconnected internal layouts (e. g., bulk storage compartments blocking off access to the waterfront) or narrow access points that created operational bottlenecks. Thus, this precondition ensures that the TPT is not merely able to lift cargo off a vessel but can complete the essential movement from quay to shore-side handover reliably.

Score	*Definition*
+3	*Access is clear and uninterrupted, either because the set-down point is adjacent to the quay or because an agreed-upon internal route allows equipment or vehicles to move smoothly between operational areas.*
+2	*Access is possible but requires minor adjustments, such as opening a gate that is normally closed, repositioning small barriers, or arranging limited temporary traffic management within the site.*
+1	*Significant changes or layout configurations are required, such as modifying internal infrastructures and/or fencing, installing new gates/access points, establishing a multi-party right-of-way or creating a dedicated corridor.*
−∞	*No feasible route exists or can be created through reasonable means, such as when buildings or immovable structures block all possible paths between the quay and any viable storage or handover point.*

5.4.2.4. SHIP-TERMINAL INTERFACE

The waterway interface precondition concerns itself with perhaps the most fundamental requirement of all: the ability for a vessel to safely moor and be attended along the quay. This includes the physical integrity of the quay edge, the presence and adequate spacing of bollards or cleats, the ability to install or use fendering, and the possibility for cargo-handling equipment (or personnel) to attend to the ship safely. The analysis showed that many potential sites were eliminated not because of shortcomings inland, but because the waterfront itself could not reliably host a vessel. This was either due to missing fixtures, severe overgrowth obstructing access, unstable or deteriorating edges, or insufficient quay length that prevented the ship from aligning with the quay. Since every TPT operation begins with a vessel call, the waterway interface sets a strict feasibility threshold: if a vessel cannot moor and be accessed safely, no subsequent handling, storage, or coordination can compensate.

Score	*Definition*
+3	*The quay can already receive a vessel safely: bollards or cleats are present, the edge is sound, fendering is available or easily added, and only minimal housekeeping would be needed.*
+2	*The quay is fundamentally workable but requires small, low-cost interventions, such as installing a few supplementary bollards, attaching portable fenders, or clearing minor vegetation to open up the bays used for loading and unloading*
+1	*The quay requires substantial work before a safe call can be made, such as significant vegetation removal, quay wall repairs, or installing several missing mooring or access fixtures. These measures are feasible but require time and effort (and investment)*
−∞	*No reasonable measures could establish a safe mooring, such as sites with structural instability, severe quay deterioration, or obstructions in the waterway that cannot be resolved within the practical or economic constraints of the TPT concept.*

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5.4.2.5. TERMINAL-HINTERLAND INTERFACE

The hinterland interface precondition concerns the basic ability of trucks, terminal tractors, or other relevant road vehicles to reach, circulate within, and depart from the area where cargo handover occurs. It captures the geometric and functional characteristics of the internal road layout: whether vehicles can enter safely, turn without excessive manoeuvring, wait briefly without blocking operations, and exit without encountering deadlocks or conflicts. This precondition is not about regional connectivity or road capacity at a city scale, but about short-range circulation patterns and the immediate internal and external geometry that determines whether handover can operate predictably. The analysis showed that many candidate sites were limited not by quay quality but by narrow entry throats, insufficient turning radii and/or shared access lanes that mixed heavy freight with "normal" traffic. A TPT can only function when vehicles can approach the quay seamlessly without obstructing themselves or others. Thus, this precondition is central to operational reliability.

Score	*Definition*
+3	*The site already provides a workable circulation pattern with adequate throat depth and a small staging area for vehicles awaiting handover, typically configured as one-way traffic loops or sufficiently wide two-way accesses*
+2	*The site's geometry is tight but still manageable through minor adjustments, such as relocating curbs, adding markings, or using simple marshalling to prevent vehicles from meeting at constrained points*
+1	*Substantial geometric or civil changes would be needed, such as widening access roads, relocating gates, re-grading surfaces, or restructuring internal layouts in a way that requires coordination with the site's primary users*
−∞	*No feasible access route exists for the intended vehicle types, either because the only available approach is too narrow or unsafe or because operational traffic would have to cross fixed obstructions or enter circulation patterns incompatible with heavy-vehicle movements*

5.4.2.6. PUBLIC INTERFACE

The public interface precondition concerns the way in which TPT operations interact with public roads, bike lanes, pedestrian routes, and other public-use spaces situated adjacent to the quay. Many candidate sites exist in urban or semi-urban environments where public mobility corridors run directly alongside the waterfront. This precondition therefore examines whether safe and lawful temporary traffic management (TTM) can be implemented during transhipment operations to protect both the public and the operation. The analysis showed that even physically suitable quays can become operationally unworkable when public routes lie too close to the water, when pedestrian or cycling paths are primary, or when local road geometry provides no space for safe segregation. This precondition ensures that a TPT can function without creating unacceptable safety risks, legal conflicts, or disruptions to public infrastructure that the operator cannot reasonably control or mitigate.

Score	*Definition*
+3	*There is effectively no public interface at all, such as where the quay is entirely separated from public roads, walkways, or cycling routes. This means that no additional measures are needed to safeguard operations*
+2	*A public interface exist, but safe and lawful TTM can be implemented, such as traffic lights, barrier placement, or traffic wardens to manage interactions with the public*

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+1	*TTM is not legally or practically possible, but the TPT can still function through internal adaptations such as avoiding public corridors, operating exclusively in off-peak hours, or configuring all movements within a fully controlled on-site perimeter*
−∞	*No lawful or safe TTM arrangement is possible, such as locations where a major arterial road runs directly at the water's edge with no quay platform, no separation space, and no legal basis for temporary closure, and/or where housing and residential use is right next to the waterway*

5.4.2.7. LEGAL AND CONTRACTUAL PERMISSIONS

The legal and contractual permissions precondition concerns whether the TPT can lawfully operate at the chosen site and whether all relevant stakeholders formally allow TPT-related activities to take place. This includes compliance with zoning regulations, environmental rules, and any municipal or regional requirements governing waterfront use, nighttime work, or temporary infrastructure etc. Equally important, it covers contractual access rights such as explicit owner consent to use the quay, the ability to move equipment through privately controlled areas, and the establishment of necessary wayleaves for short shunts to adjacent storage or handover points, if necessary. The analysis revealed that many sites fail not on physical grounds but because they cannot be accessed, shared, or used without consent from involved stakeholders (such as adjacent landowners). Thus, this precondition ensures that a TPT stands on a robust legal and contractual footing.

Score	*Definition*
+3	*All necessary permissions are already in place: the zoning allows freight activities, the landowner explicitly consents to the intended use, and any required access rights or operating windows are formally secured*
+2	*All necessary permissions are not yet secured but can reasonably be obtained through standard permits and simple contractual agreements*
+1	*Significant legal or contractual work would be required, such as negotiating multi-party agreements, establishing new rights-of-way, or securing exceptional permissions that may affect timing and/or cost (and, thus, overall feasibility)*
−∞	*One or more critical permissions cannot be obtained at all, whether regulatory constraints prohibit the activity, the owner refuses access outright, or zoning prevents any plausible workaround*

5.4.2.8. LONG-TERM AVAILABILITY

The long-term availability precondition concerns whether the site can host TPT operations for a sufficiently long and predictable period to justify activation (and to ensure a return on investment). Even when a location meets all physical and operational requirements, it may still be unsuitable if it is subject to redevelopment, zoning changes, long-term leasing commitments, or strategic planning decisions that will convert the waterfront to non-industrial uses in the foreseeable future. The analysis revealed multiple such cases: quays that appear viable in the present but are scheduled for transformation into residential areas; plots designated for demolition or repurposing; and industrial premises whose waterfront zones are shrinking. Because TPTs depend on stable access to the quay and surrounding operational areas, this precondition ensures that the site's expected functional horizon is long enough to make activation meaningful and economically sensible.

Score	*Definition*

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+3	*The site has a somewhat stable long-term availability. That is, no planned redevelopment is expected which could potentially conflict with transhipment operations, and land-use designations support continued industrial activity*
+2	*Redevelopment of the site is expected, but the remaining available window is likely sufficient to justify a TPT (depending on expected demand and investment needs).*
+1	*Availability is short-term, such as locations within active planning zones or areas with emerging redevelopment pressure. Here, a TPT may still be justified, but only with caution and clear understanding of the limited horizon.*
−∞	*The site is formally committed to another incompatible future purpose, such as confirmed residential redevelopment. Thus, the site cannot support TPT deployment because its operational future is fundamentally incompatible with the concept.*

5.4.2.9. TRANSPORT DEMAND

The transport demand precondition concerns whether there is a credible and sufficient customer base in the site's catchment area whose logistics flows can realistically be shifted to inland waterway transport (IWT). A TPT is only viable when it can serve actual freight movements that match the characteristics of the maritime link, such as goods that can be transported in containers, suitable shipment sizes, and operational flexibility aligned with the service pattern (i.e. not fast-moving goods as observed in airborne freight). This precondition thus examines the presence of anchor shippers or clusters of small-to-medium-sized industrial actors with potential transport needs. The analysis showed that many candidate sites were physically workable but were surrounded by businesses unlikely to adopt waterborne logistics because of commodity type, time sensitivity, or the sheer size of their operation. Conversely, locations with established or latent IWT use tended to offer more predictable foundations for TPT deployment (such as waste managers, building-materials suppliers, and manufacturing companies in general). This precondition ensures that a TPT is not established on speculative assumptions but is grounded in (assumed) transport demand.

Score	*Definition*
+3	*Committed or near-committed volumes already exist from one or more larger anchor shippers who, on their own, can provide sufficient freight to fill one or more vessels without relying on additional bookings*
+2	*Interest is strong and letters of intent (may) have been issued, but no formal commitment has been made. Minor orchestration is required, typically involving the consolidation of regulator, moderate flows from several mid-sized shippers to achieve a stable service*
+1	*Demand is fragmented, exploratory, or otherwise immature, such that substantial commercial development would be needed to achieve viability. Activation would depend on extensive market development, risk-sharing arrangements, and/ or the introduction of an innovative consolidation mechanism.*
−∞	*No plausible or addressable demand exists, such as where industrial actors have no transport demand (or their transport is structurally unsuitable for IWT), where potential anchors have expressed disinterest, or where volumes are so sporadic that even seasonal operations cannot be justified*

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5.4.3. THE BUILDING BLOCKS OF THE TPT CONCEPT

Through the analysis of the TPT opportunity areas within the MSOAs, the identification of common denominators and patterns across these areas and the preconditions that must be present in order to erect a TPT concept, the following TPT building blocks have been identified (see Table 5-1). Each building block comes with different configurations such that the TPT concept becomes modular and highly adaptable to both the physical, operational and social context in which it is to be deployed.

Table 5-1 TPT building blocks

Building Block	Block Configuration
A. Cargo Handling	A1. Ashore, mobile cargo handling A2. Ashore, fixed cargo handling A3. Afloat, fixed cargo handling A4. Afloat, mobile cargo handling
B. Cargo Storage	B1. On-quay cargo storage B2. Floating cargo storage B3. Remote cargo storage B4. Ecosystem cargo storage
C. Site Utilities	C1. Absent site utilities C2. Temporary site utilities C3. Permanent site utilities
D. Waterborne interface	D1. Minimal enablement D2. Shoreside enablement D3. Waterside enablement
E. Hinterland interface	E1. Last-mile delivery E2. Direct delivery E3. Self-service pick-up
F. Public Interface	F1. Open access F2. Limited access F3. Restricted access
G. Temporal Availability	G1. Continuous availability G2. Constrained availability G3. Contingent availability
H. Operating Model	H1. Independent TPT H2. Integrated TPT H3. Ecosystem TPT

Each of these building blocks along with their various configurations will be explained below.

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5.4.3.1. A. CARGO HANDLING

Cargo handling lies at the heart of the TPT concept as it determines how containers move between the AUTOFLEX vessel(s), the quay(s), the storage area(s), and the hinterland transport mode(s). Because inland terminals vary widely in layout, infrastructure, and operational demands, cargo handling must be modular and flexible to be deployed within the wide variety of sites. The building block distinguishes equipment based on two key dimensions: whether it is positioned *ashore* or *afloat*, and whether it is *fixed* or *mobile*. These dimensions create four distinct quadrants which each representing a unique operational approach: *Ashore Fixed*, *Ashore Mobile*, *Afloat Fixed*, and *Afloat Mobile* cargo handling.

A1. Fixed, ashore cargo handling: This category comprises cargo-handling equipment that is permanently installed on land and dependent on substantial supporting infrastructure. It includes classic quay cranes anchored directly to the quayside as well as rail-mounted cranes that can move only along pre-installed tracks. Although rail-mounted cranes have some mobility, their reliance on fixed rail infrastructure places them firmly within the "fixed" category for this study. Such equipment is common in inland terminals, particularly at bulk-handling sites where continuous, heavy-duty lifting is required. Fixed cranes offer stability, clearly defined operational zones, and efficient handling of large cargo volumes. Several examples were identified during the analysis: classic fixed cranes were observed at the Avalex recycling centre (Delft), the Mebin facilities in Haven de Krouwelaar (Breda), and at the ABZ premises in Eindhoven. Rail-mounted cranes were documented at NV HMS (Den Haag) and at the Mebin/Weber Beamix site (Eindhoven), illustrating their continued relevance in inland logistics.

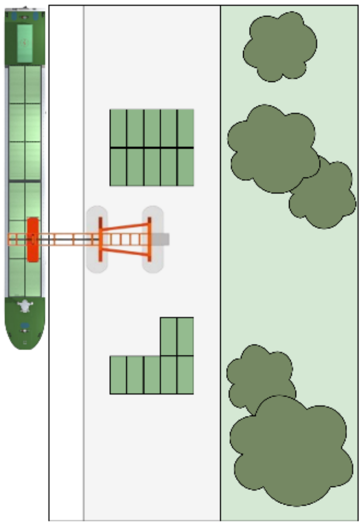

Figure 5-97 A1

A2. Mobile, ashore cargo handling: This category encompasses land-based cargo-handling equipment that can move freely across a terminal, enabling operators to position machinery wherever it is most effective. Typical examples include wheeled cranes such as reach stackers or tracked diggers, which are widely used for lifting, transporting, and stacking containers or bulk materials respectively. Their high degree of mobility and limited dependence on dedicated infrastructure make them a flexible and cost-efficient solution for many inland terminals. These machines are particularly valuable in environments where operational demands fluctuate or where space constraints require adaptable handling strategies. In the analysis, mobile cranes were observed at the Breure Grondwerken premises in Roosendaal, where they support smooth transshipment between vehicles and nearby storage areas. Comparable practices were noted along the Delftse Schie in Delft, where wheeled cranes are employed for a variety of handling tasks. Their versatility allows terminals to respond quickly to changing cargo flows, enhancing both efficiency and operational resilience.

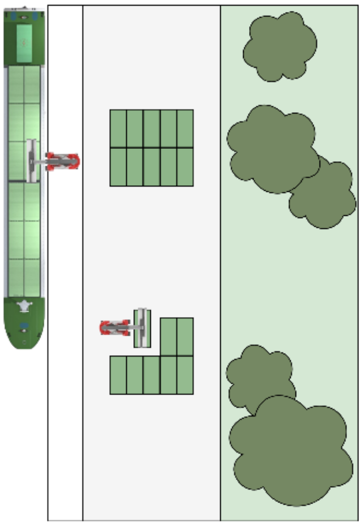

Figure 5-98 A2

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A3. Fixed, afloat cargo handling: This category refers to cargo-handling equipment mounted on floating structures, such as barges, that remains essentially fixed relative to the barge on which it is installed. These afloat cranes combine the lifting capacity of shore-based systems with the advantage of being positioned directly on the water, making them particularly valuable in locations where useable quayside infrastructure is limited. Historically, such installations were common on inland waterways, providing a practical means of transshipment without requiring extensive land-based construction. These were used at several sites such as in *Haven van Rijswijk* in Den Haag, the *Delftse Schie* in Delft and at the *Dycore* premises in Breda, where barges equipped with fixed cranes are seen performing routine cargo-handling tasks along the waterfront. These examples highlight the longstanding role of fixed afloat equipment in supporting flexible and space-efficient inland logistics.

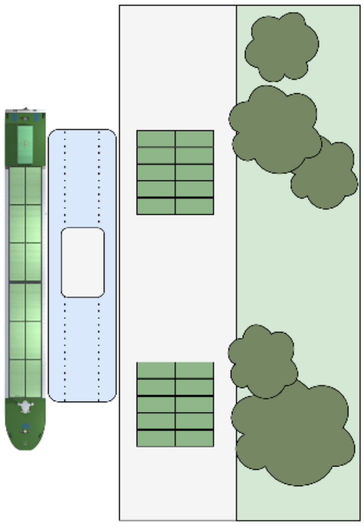

Figure 5-99 A3

A4. Mobile, afloat cargo handling: This category encompasses cargo-handling equipment that operates from floating platforms—such as barges or pontoons—while retaining the manoeuvrability of land-based machinery. Typical examples include wheeled cranes like reach stackers and, in some instances, rail-mounted cranes temporarily positioned on a floating structure. These machines can move across the deck of the barge to achieve optimal lifting positions and, in certain configurations, may even travel between the floating platform and the quayside via a ramp. This capability enables seamless transitions between afloat and ashore operations, providing a high degree of operational flexibility. Such hybrid setups are particularly useful in locations with limited fixed infrastructure or where spatial constraints prevent the installation of permanent quay-side cranes. Their adaptability allows operators to tailor handling capacity to changing needs without major infrastructure investments. This configuration was observed at the quay in Zijlkwartier (Leiden) and along the Delftse Schie in Delft, where mobile cranes mounted on barges supported efficient, versatile transshipment activities across varying site conditions.

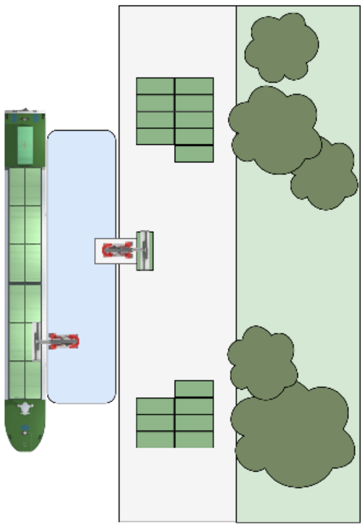

Figure 5-100 A4

Thus, a clear typology for cargo-handling configurations within TPTs is established based on how equipment location and mobility shape operational possibilities. Fixed ashore equipment, such as shore cranes, offer stability and high-capacity handling, while mobile ashore equipment, such as reach stackers, provides flexibility for dynamic terminal environments. Fixed afloat equipment, such as craned barges, extend lifting capability directly onto the water, particularly where quayside infrastructure is limited, whereas mobile afloat equipment, such as reach stackers "living" onboard a barge with a ramp that enables it to move ashore when needed, combine mobility with a water-based spatial footprint. Together, these four configurations illustrate the diversity of the cargo handling strategies deployed in the TPT concept.

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5.4.3.2. B. CARGO STORAGE

Cargo storage forms the buffering backbone of the TPT, shaping how effectively vessel operations can be decoupled from just-in-time (JIT) last-mile transport. The characteristics of the (potential) storage areas across the analysed sites range from spacious industrial yards to narrow quay strips, remote or ecosystem-based plots, and fully water-based environments. Thus, a modular building block that addresses this variety must be developed and should distinguish between four configurations: *On-Quay*, *Floating*, *Remote*, and *Ecosystem* storage solutions, each reflecting a different spatial and operational relationship between storage and transshipment. This in turn ensures that the overall performance of the transshipment processes of the TPT concept is maximised to the context into which it is deployed.

B1. On-Quay storage: This configuration involves storing cargo units directly on the quay or immediately adjacent to it, ensuring minimal distance between storage and transshipment points. It represents the standard operating model for most terminals in both seaport and inland port contexts, as it allows rapid, predictable cargo flows and reduces the handling steps required during loading and unloading. Many sites examined in this study follow this conventional approach. A more innovative variant was observed along the Delftse Schie, where a height-based on-quay storage system is used for bulk cargo. In this setup, materials are kept in elevated compartments positioned over a designated truck lane. Trucks drive beneath these compartments, which can be opened to release the stored bulk material directly into the trailer below. This method significantly reduces coordination demands between storage and transshipment, as cargo can be dispatched quickly and efficiently on demand. Where space permits, such solutions enhance throughput and streamline quay-side operations.

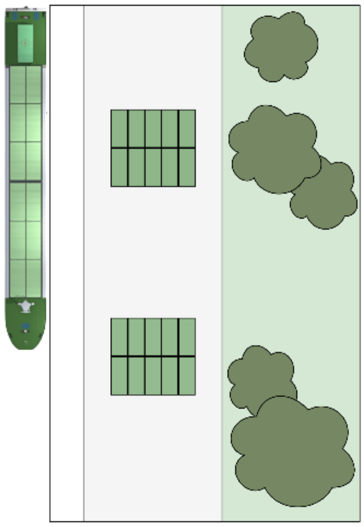

Figure 5-101 B1

B2. Floating storage: This configuration involves storing cargo units directly on barges or floating platforms that are moored alongside the quay. Although less common than traditional land-based storage, floating storage offers a flexible solution in areas where quayside space is limited or where temporary buffer capacity is required. It allows operators to adjust storage volume simply by adding or moving barges, making it particularly useful for activities with fluctuating demand or irregular cargo flows. Several instances of this setup were identified in the analysis. In Industriehaven in Haarlem, a waste management operator relies on barges moored next to the quay to hold collected waste before onward transport. A similar approach was seen in Leiden, where a barge rental company maintains a line of moored vessels that effectively function as floating storage units. In Belcrumhaven in Breda, additional barges serve as overflow storage, supporting local logistics operations. Overall, floating storage enhances operational adaptability while reducing dependence on fixed land-based infrastructure.

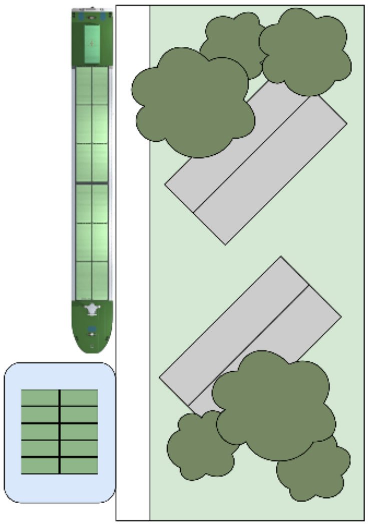

Figure 5-102 B2

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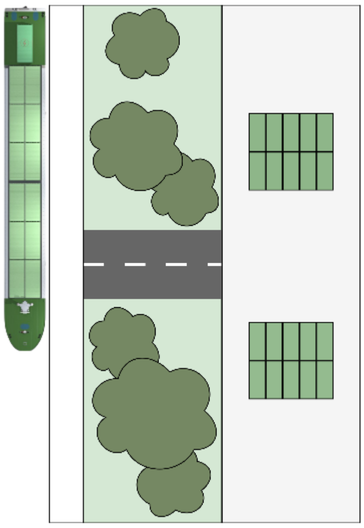
B3. Remote storage: This configuration refers to cargo being stored at an on-shore location that is not directly adjacent to the transshipment area, creating a spatial separation between storage and handling activities. Remote storage can serve as an effective solution when quay-side space is limited or when additional buffer capacity is required beyond what is available at the TPT itself. This arrangement was identified as a potential option for the brownfield site along the Noorder Buiten-Spaarne canal (Haarlem), where a nearby container depot could function as an external storage area. Similar opportunities were noted near the Trekvliet Bridge, where an empty storage zone is located further down the quay, and at both Haven van Rijswijk sites, each of which has a sizable unused area within proximity. Observations also revealed possibilities for hybrid configurations, such as at the Karlshoven pier in Haven de Krouwelaar (Breda), where remote storage is combined with waterborne storage solutions to enhance operational flexibility.



B4. Ecosystem storage: This configuration conceptualizes the wider industrial area surrounding the TPT as a unified storage ecosystem, divided into designated zones for individual actors similar to how major seaport terminals allocate areas based on cargo characteristics, onward transport mode (road, rail, or water), or special handling requirements such as dangerous goods or reefers. Like remote storage, ecosystem storage situates cargo away from the quay. However, it differs fundamentally in its level of integration. Whereas remote storage functions as a neutral drop-off/pick-up area accessible to third parties for first- or last-mile activities, ecosystem storage embeds storage directly within the operational premises of one or more industrial actors. In doing so, it effectively eliminates the last-mile stage, as cargo moves directly between the actor's facilities and the TPT without external intermediaries. Consequently, ecosystem storage is not open to third-party use but is tailored to the specific logistical needs of the participating industrial actor(s).

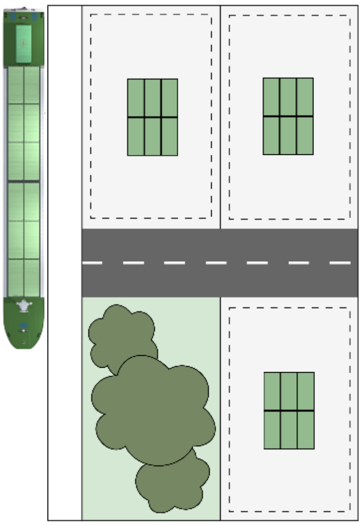


Figure 5-103 B4

Thus, four modular storage configurations that define how TPTs buffer cargo and manage operational decoupling have been defined. *On-Quay storage* supports rapid, predictable flows by placing cargo directly at the transshipment interface, while *Floating storage* offers adaptable capacity where land is constrained. *Remote storage* provides additional buffer space beyond the quay and, potentially, enable scalable operations if shunts can be coordinated correctly, and *Ecosystem storage* embeds cargo within the premises of the actors within the broader industrial ecosystem and eliminate last-mile movements altogether. Together, these configurations illustrate the diverse spatial and logistical strategies available within the TPT concept and demonstrate how storage design can enhance flexibility and efficiency within wider industrial environments.

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5.4.3.3. C. SITE UTILITIES

Site utilities form the essential technical backbone of a TPT, determining whether operations can be carried out safely, predictably, and across varying temporal and/or environmental conditions. Candidate sites differ widely from fully serviced industrial terminals to brownfields with little to no utilities. Consequently, the TPT concept defines a site utility building block and distinguishes between three utility configurations: *Absent*, *Temporary*, and *Permanent* utilities. These configurations reflect increasing levels of infrastructural support, from relying solely on ambient conditions to deploying modular systems or embedding utilities within existing industrial operations. Utility provision thus shapes operational continuity and the adaptability of TPTs across diverse inland environments.

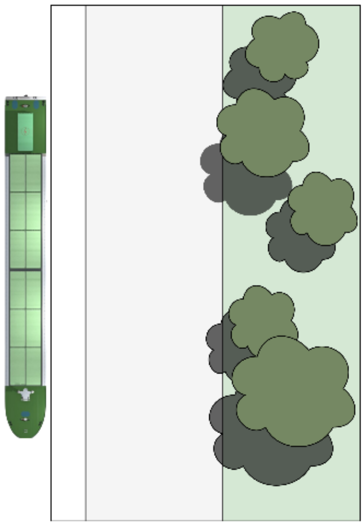

Figure 5-104 C1

C1. Absent: A configuration where the TPT only functions with no added utilities. This means, for instance, that the TPT will function only during daylight hours when the sun is up and provides the basic lighting function. Similarly, there will be no provision of power. The configuration therefore relies entirely on existing ambient conditions and requires no on-site technical installations or setup, which makes them suitable for minimal-infrastructure sites or where locations must coexist with potentially light- or sound-sensitive surroundings (such as in residential areas). Cargo handling equipment will depend on energy (or fuel) supply, and in the case where such utilities are absent, it implies that an energy supply service will be needed. Either a vehicle can regularly visit the TPT to refuel/charge the equipment, or if such utilities are found at a nearby location, equipment such as a reach stacker or tug master could potentially drive to resupply. The *Absent* utilities configuration could be an easily applicable solution in many of the "open" quay sites seen in the analysis, e. g., on the *Delftse Schie* (*Delft*), in the *De Waard* and in the *Zijlkwartier* district (*Leiden*) as well as the many brownfields. It could also be an easy solution at sites such as the shopping centre at Zoeterwoude-Rijndijk (Leiden) or the multi-business complex at Haven van Rijkswijk (Den Haag). However, this does not prevent TPT constellations at these sites with more advanced utility configurations.

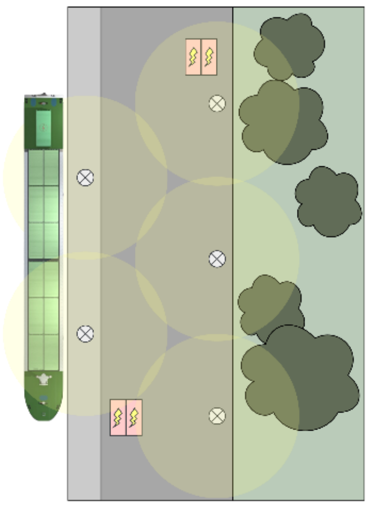

Figure 5-105 C2

C2. Temporary: A configuration where mobile and/or modular utility systems are introduced, such as portable lighting, generators or battery-based power supply (e. g., containerised batteries) that could potentially be provided with the incoming vessel. This allows the TPT to operate in environments with limited available utilities, such as those described in C1., but with added utilities so that the TPT operational envelope can be extended beyond the constraints set by the "as-is" setup of the site (e. g., that operations can only take place during daylight due to the lack of lighting utilities at the site). For energy supply to cargo handling equipment, ZES packs or mobile fuel tanks can be used. This could be deployed to any of the above sites to extend the scope of their operations and reduce dependency on external power supply for equipment, without committing to permanent infrastructural upgrades. This would work particularly well in areas where utilities are absent, but where a

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certain level of public accessibility control can be safeguarded so that the mobile and modular utility systems are not falling victim to vandalism or theft. Such sites could be the distribution centres facing the waterways, such as DHL and/or Xorta sites in Roosendaal, the Ubiquity and/or Rhenus sites in Eindhoven or the DB Schenker site in Breda. It may also be interesting for sites like the waste and recycling centre in Industriehaven te Haarlem, the central pier business complex in Binckhorsthaven (Den Haag) or the bike depot and storage area next to the Trekvliet Bridge (Den Haag).

C3. Permanent: A configuration where the utilities of the TPT is integrated into the existing operations and activities at sites that already possess industrial-grade utilities or where investments in permanent utilities are feasible. This allows the TPT to operate continously and, arguably, more efficiently. In practice, this means using already exiting light and power sources (e. g., grid connection), extending these utilities by adding additional lamps and power outlets where needed or investing in an entire utility-setup from scratch, including lighting, power etc. One could argue that this latter solution may remove the *temporary* aspect of a TPT, but it could theoretically work at sites where multiple actors have interest in developing more permanent utilities and can share the site temporally (e. g., a day/night or weekday/weekend share). From the analysis, this TPT constellation would be exemplified at sites such as, presumingly, all the bulk terminals identified as well as e. g., the DSM-Firmerich plant Gist- en Spiritusfabriek te Delft, the Brand Master site in Haven de Krouwelaar (Breda) and the NV HMS Waste management centre in the Binckhorst District (Den Haag).

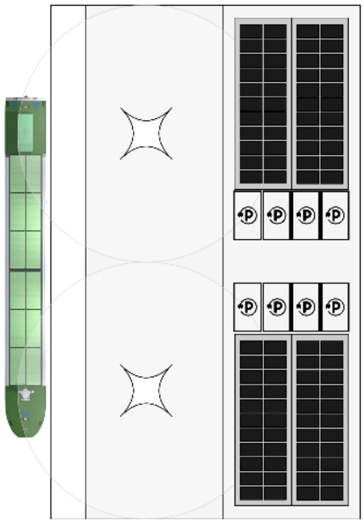

Figure 5-106 C3

Thus, three utility configurations that define how TPTs operate within different infrastructural contexts have been defined. *Absent site utilities* rely entirely on ambient conditions and external energy supply; *Temporary site utilities* introduce mobile lighting and power systems and as such extend the operational hours and reduce dependence on fixed infrastructure; while *Permanent site utilities* represent the most advanced configuration whose lighting and power utilities are embedded directly into existing industrial setups to enable continuous, efficient operations. Together, these configurations illustrate how utility provision influences operational scope, investment needs, and site suitability, allowing the TPTs to be deployed across with varying levels of utility availabilities.

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5.4.3.4. D. WATERWAY INTERFACE

The waterway interface is a central building block of the TPT as it defines how an inland vessel physically "interfaces" (i.e. connects) with a site so that transhipment can occur. Unlike the precondition concerning waterfront status, the building block treats the interface as an operational and financial design choice. Said differently, while a precondition may exist, it is within the choice of the actor deploying the TPT to decide whether the nature and context of the logistics needs that the TPT attempt to address require or will be better suited with a given type of waterborne interface configuration. Three configurations are distinguished: Minimal, Shoreside, and Waterside enablement. Each represents a different approach to mooring, ranging from ad-hoc, low-impact arrangements to fully supported shoreside systems and floating mooring structures.

D1. Minimal enablement: This configuration refers to fast, easy, ad-hoc exchanges where the AUTOFLEX vessel is hold only minimally alongside – either as a result of station-keeping DP systems onboard the ship, if possible, or from a couple of stabilizing lines to available appendages or informal mooring points. This solution works well at sites with water facing promenades that are used during the daytime and, at least partly, provide an aesthetic element to the architecture at the site (i.e. it may not be possible to "fill" these sites with mooring bollards etc.). From the analysis, this includes sites such as the shopping centre in Leiden, the central pier in Binckhorsthaven (Den Haag), and the multi-business waterfront in Haven van Rijkswijk (Den Haag). The minimal configuration is good for shorter dwelling times and more ad-hoc and/or laissez-faire approaches, and could be seen combined with more modest, opportunistic and seasonal flows.

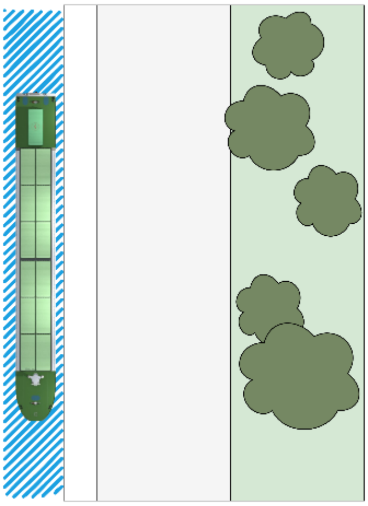

Figure 5-107 D1

D2. Shoreside enablement: This configuration refers to THE shoreside mooring system constellations and is how many inland terminals function today wherein the vessel is properly moored to the quay using existing or potentially enhanced shore-side facilities such as bollard, fendering etc. (or perhaps more advanced technical systems such as auto-mooring). This solution works well when higher volumes are expected and the vessel needs to be securely moored so that transhipment operations can be undertaken as efficiently as possible. This also requires that the vessel can be moored in its entirety parallel to the quay. From the analysis, this configuration is observed in most bulk transhipment terminals as well as sites where inland ships are seen moored in a waiting or resting position, such as in Haven de Krouwelaar (Breda) and Belcrumhaven (Breda), or on the exemplary Delfte Schie transhipment operations.

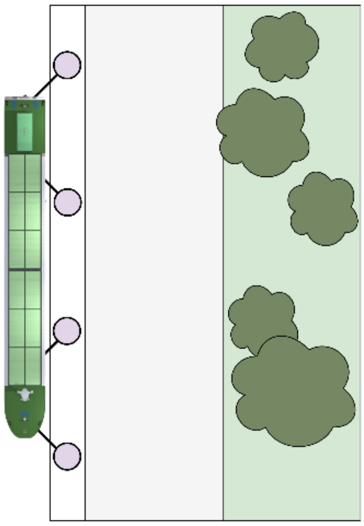

Figure 5-108 D2

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D3. Waterside enablement: This configuration refers to sites where the quay is either not long enough to accommodate the vessel or where for some reason the ship will not be able to berth in its full length along the quay, but where more "formal" mooring arrangements are needed beyond the Minimal configuration. Consequently, the mooring face is provided "afloat", typically via spud-barges or modular pontoons which themselves are more permanently pinned in place – either via legs that touch the riverbed or alternative forms of more "fixed" arrangements with shore. Access from the mooring pontoon to the quay is provided via a ramp, or similar, which enables a vessel-to-pontoon-to-quay constellation. This decouples TPT feasibility from fixed quay geometries and enables effective full-length mooring of vessels in places where the quay is otherwise too short or partly obstructed. This building block could potentially be combined with water-based cargo handling and cargo storage configurations, essentially creating an almost entirely water-based TPT constellation with close to no shoreside footprint. From the analysis, this mooring configuration could potentially be deployed at places such as the small quay next to the first Jon Guyt location in Heen Industrial Park (Leiden) or similar sites.

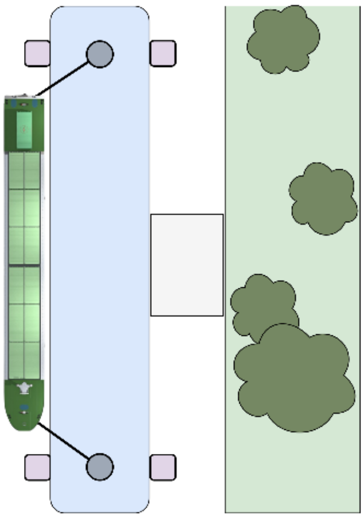

Figure 5-109 D3

Thus, three waterway interface configurations that shape how vessels access TPT sites have been defined. Minimal enablement supports short, flexible, low-infrastructure exchanges suited to aesthetically significant and/or publicly accessible waterfronts. Shoreside enablement reflects the conventional inland terminal model and provides secure, full-length mooring for efficient and higher-volume operations. Waterside enablement introduces floating mooring structures through spud barges or similar that overcome quay length or geometric constraints and thereby enable full-length berthing even where shoreside space is limited. Together, these configurations demonstrate how mooring design can expand TPT applicability, allowing operators to tailor waterborne access to site characteristics, operational needs, and investment considerations.

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5.4.3.5. E. HINTERLAND INTERFACE

The hinterland interface represents the final stage of the TPT transhipment process as it determines how cargo continues its journey once it leaves the vessel–quay–storage TPT system. While earlier building blocks govern internal cargo handling processes, this interface defines the outward-facing processes that connects with surrounding logistics networks and end users. The TPT concept distinguishes three configurations: Last-mile delivery, Direct delivery, and Self-service pick-up. Each reflects a different degree of integration between the TPT and its hinterland, ranging from conventional truck-based distribution to fully embedded industrial setups and customer-driven collection models.

E1. Last-mile delivery: A configuration that represent the most "conventional" hinterland interface, where cargo is transferred from the TPT to trucks or other last-mile vehicles for delivery into the surrounding area – either by a third-party logistics company or by the AUTOFLEX transport system itself. In a nutshell, the transport has not been finalized after the cargo leaves the TPT. TPTs with on-quay storage, i.e. more "conventional" TPTs, are well suited for this configuration as is particularly TPTs with remote storage areas as they allow short-cycle pick-up operations that decouple cargo handling from last-mile deliveries. This configuration is relevant for most sites that have the available space and temporal buffer to allow for third party transport operators to access the TPT storage areas, pick-up the cargo and drive it onwards into the transport chain without the risk of the entire TPT being held back from potentially late truck arrivals – and similarly, with predictable TPTs that do not force the truck to wait prolonged time before being able to pick up the cargo.

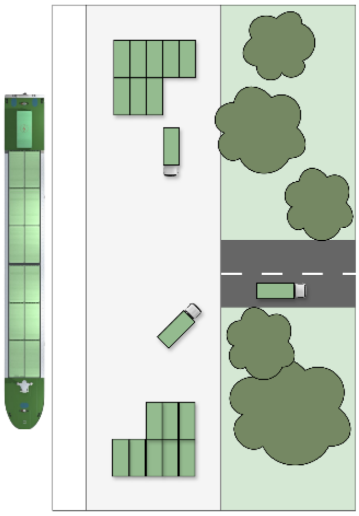

Figure 5-110 E1

E2. Direct delivery: A configuration that represents a more integrated supply chain wherein the TPT is directly embedded within or adjacent to the premises of the final recipient of the cargo, which eliminates last-mile delivery entirely. In a nutshell, this means that the transport is finalized whenever it has been delivered to the TPT storage area (whether on-quay or remote). This configuration is an obvious choice in a fully integrated operating model with a single customer, wherein the TPT is an integrated component of the industrial site at large with seamless cargo movement between vessel, storage and production (and vice versa). However, the configuration also works with the ecosystemic approach (storage and operating model) as the main aspect of the direct delivery configuration is that the final recipient of the cargo is located within the premises of or in the close vicinity (i.e. within the MSOA) of the TPT.

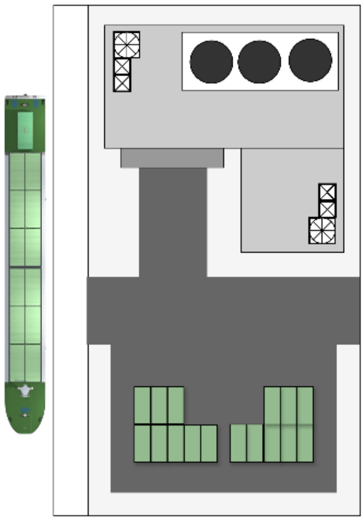

Figure 5-111 E2

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E3. Self-service pick-up: A configuration where customers themselves collect cargo directly from the TPT storage area during designated operating windows. Opposite the last-mile delivery configuration, the transport service is similar to the direct delivery configuration, deemed completed when it arrives at the TPT. In practice, this works similar to the B2C market, wherein private customers often collect their purchases at a nearby package box. This configuration is well-suited for small and medium-sized actors who have modest or occasional/seasonal freight flows and prefer to manage their own pick-up rather than establishing formal last-mile delivery arrangements. While this configuration could be combined with both on-quay and remote storage configurations, it is advisable not to have the pick-up process in any way interact with the transshipment process as this may significantly increase transport lead times for the remaining cargo and potentially risks overall feasibility of the transport system at large.

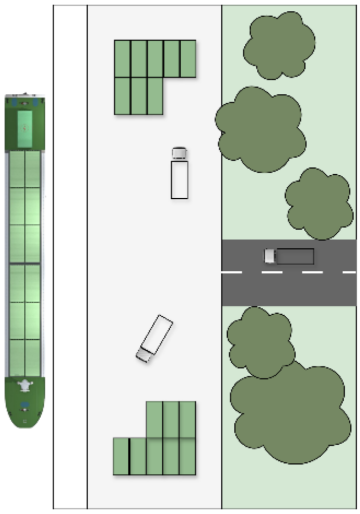

Figure 5-112 E3

Thus, three hinterland interface configurations have been defined which in different ways determine how cargo leaves the TPT and enters the wider logistics chain. Last-mile delivery supports conventional distribution models and enable third-party or AUTOFLEX-operated last-mile transports to complete the final part of the transport journey. Direct delivery eliminates the last-mile entirely by situating the TPT within or right adjacent to the final consignee's (or consignor's) premises, thus creating a seamless, integrated flow of goods to/from an industrial site in question. Self-service pick-up offers a flexible alternative, especially for smaller actors, as it allows customers to pick-up their cargo(es) themselves at the TPT during designated operational windows. Together, these configurations illustrate how hinterland design choices influence accessibility, integration, and the overall efficiency of TPT-enabled transport systems.

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5.4.3.6. F. PUBLIC INTERFACE

The public interface refers to the degree to which the TPT is accessible for and must account for the general public as this determines potential safety and security measures that the TPT must ensure in order to operate properly. The analysis revealed that the candidate sites are embedded either varying zoning context, ranging from confined industrial to dense residential areas, and thus this building block distinguishes between three configurations of public interface and the subsequent need to install safety and security safeguards at the TPT site: Open, Limited, and Restricted access. It is important to note that this building block does not define the present access at the site in question, but the safeguards that can be established to safeguard a certain level of access control.

F1. Open Access: A configuration where minimal effort is being placed to monitor, control and/or prevent access to the TPT site. As such, the site can be considered more or less entirely "open" to the public and potential third parties. Examples from the analysis includes all openly accessible quay sites – some of which have or have had been the site of transshipment operations. This includes the example on the Delftse Schie as well as locations such as two public quays in Leiden where the Oude Rijn and Rijn-Schiekanaal intersects, the Karlshoven pier in Breda (currently used not for transshipment but, it appears, as a waiting quay for bulk ships bound for the Dycore or the Mebin site) and the Belcrumhaven in Breda, where ships are seen berthed more "indefinitely". This requires some coordination on the part of the TPT but is a quick and easy approach to begin transhipment immediately. While it may sound too lenient an approach, the impressive example from Deltse Schie proves that it is possible under the right circumstances.

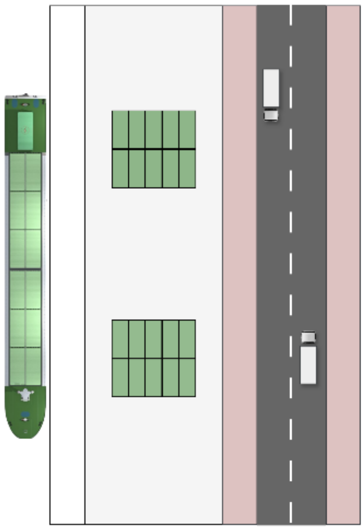

Figure 5-113 F1

F2. Limited Access: A configuration where access is limited, e. g., by the erection of a fence or similar access barriers which enable the TPT to monitor and control access to the premises to some extent. Examples from the analysis include sites such as the unused quay in the *Zijlkwartier* district in Leidendorp (on the intersection between Oude Rijn and Rijn-Schiekanaal), where historical images indicates a transhipment operation somewhat similar to that of the Deltse Schie exemplary case, but with the erection of a minor, mobile concrete barrier that prevents accidental intrusion into the site from third parties. Other examples include the industrial area of Best where a minor fence blocks off the parking area, i.e. the TPT transhipment area. However, some areas show the range of the *Limited Access* configuration. For instance, the quay area between *Heidelberg Materials* and *Jon Guyt* in *Industrieterrein 't Heen (Leiden)* is relatively accessible to the public, but it is fair to assume that access has been limited to some extend based on the nature of the ongoing operation there. This could be enforced through some kind of coordinated restriction efforts either via traffic wardens or temporal fencing similar to the historical use of the quay in Zijlkwartier. Thus, this quay in the *Industrieterrein 't Heen (Leiden)* shows the "lighter" end of

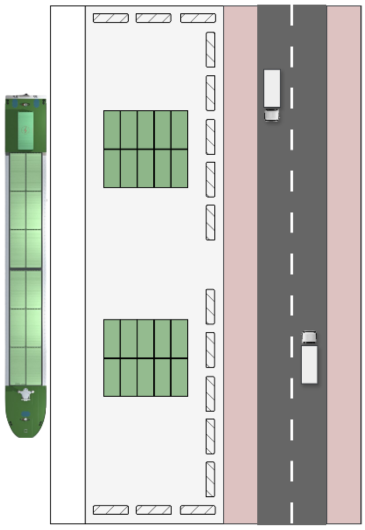

Figure 5-114 F2

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the *limited access* configuration which borders on the *open access*. At the other end of the scale, the bike depot and storage area next to the *Trekvliet Bridge* (in the *Binckhorst District*, *Den Haag / Delft*) is also considered *limited access* because even though there is fencing provided around both the potential transhipment area and the potential storage area, there is an "open-access" section in between these two sites which will have to be managed in some shape or form (again, possibly through traffic wardens or mobile fencing). Thus, this site in the *Binckhorst District* shows the "tougher" end of the *limited access* configuration which borders on the *restricted access*.

F3. Restricted Access: A configuration where access is confined through advanced perimeter fencing and controlled through a central gate that manages in- and outgoing vehicles. Examples from the analysis includes sites such as the Brand Master site in Haven de Krouwelaar (Breda), the impressive DSM-Firmerich plant in the Gist- en Spiritusfabriek (Den Haag / Delft) and the various bulk terminals in general. These are all sites where well-established access restrictions are in place and thus the sites can guarantee that no third parties, whether accidental or deliberate, will access the site without permission from the manager(s) of the site themselves. Furthermore, the outer perimeter of entire industrial sites could potentially be closed off entirely, as can be seen e. g., in some of the industrial areas around the airports (Schiphol and Eindhoven). This enables the monitoring and control of access in and out of the area at large, which would enable *restricted access* configurations in tandem with e. g., the *remote storage* and the *ecosystem storage* configurations. An example of this could be the central pier in the *Binckhorsthaven* (including the *Titaan*, *Caballero Fabriek* and *Loetje*) or, contingent on a larger effort of managing the relatively few access roads, in *Heen Industrial Park (Leiden)* or *Best Industrial Park (Eindhoven).*

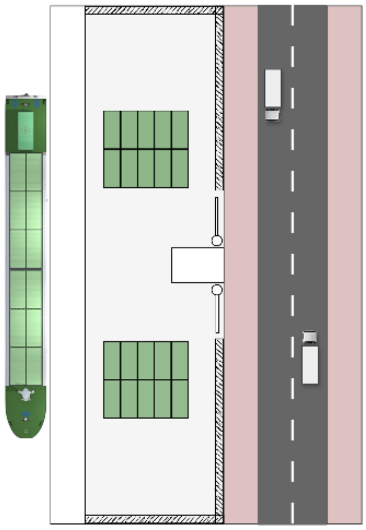

Figure 5-115 F3

Thus, three public interface configurations have been defined that determine how access to the TPT is managed. Open Access allows operations within publicly accessible spaces and relies on operational coordination rather than physical barriers. Limited Access introduces fencing or temporary controls to manage interactions between the public and TPT activities, hereby offering a flexible middle ground between fully open and fully closed sites. Restricted Access provides full perimeter control through gates and secure fencing, which is typical of established industrial sites and terminal today. Together, these configurations illustrate how access management influences safety, security, and operational predictability, and thereby allowing TPTs to function effectively across various access environments ranging from open waterfronts to fully enclosed industrial zones.

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5.4.3.7. G. TEMPORAL AVAILABILITY

Temporal availability defines when a TPT can operate at a given site and is a core determinant of its feasibility, efficiency, and interaction with surrounding land-use patterns. Because many candidate sites sit within mixed-use environments, TPT operations must align with existing operational "rhythms" to avoid disrupting and/or congesting ongoing activities within the broader context in which it is deployed. Temporal availability also shapes the configuration of other building blocks, such as public access management and utility provision. The TPT concept therefore distinguishes three configurations: *Continuous*, *Constrained* and *Contingent*. Each reflect different levels of operational flexibility.

G1. Continuous: A configuration akin to standard terminal operations, where the site of the TPT can be access and used at all hours. This is typically within fenced industrial zones or logistics premises whose operational "rhythms" already can accommodate transhipment operations and the movement of industrial vehicles such as reach stackers etc. throughout the entire day and night. This configuration fits well into sites that are anchored by a primary or single tenant, such as the DSM-Firmerich plant Gist- en Spiritusfabriek te Delft, the Brand Master site in Haven de Krouwelaar (Breda) and the NV HMS Waste management centre in the Binckhorst District (Den Haag) or the distribution centres facing the waterways, such as the DHL and/or Xorta sites (Roosendaal), the Ubiquity and/or Rhenus sites (Eindhoven) or the DB Schenker site (Breda).

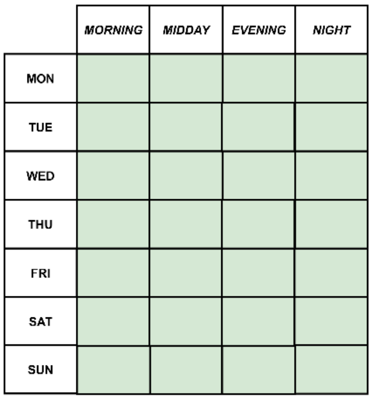

Figure 5-116 G1 (example)

G2. Constrained: A configuration that reflects the operational patterns of sites that are not continuously available for TPT purposes, e. g., due to daily business-related activities or general opening hours of the site as well as potential public road interfaces and nighttime noise restrictions in more residential areas. A long list of sites from the analysis could be available for TPT purposes *outside* of the opening hours of the anchor tenant. This includes both daily and weekly temporality, i. e., using the site at night or at weekends, respectively, when it is otherwise closed. While night-based TPT operations would need to be paired with a sufficiently advanced level of the *Site Utilities* block, weekend-based TPT operations could remain active only in daylight. Similarly, night-based operations may be limited by noise-restrictions while weekend-based operations would not. Oppositely, night-based TPT operations increases potential availability and flexibility of the site and would potentially minimize the TPT's exposure to public interference, which the weekend-based TPT operations would not. While the aforementioned "single tenant" cases could offer continuous temporal availability, it may be that the tenant themselves would want a *constrained* model to ensure that transshipment operations does not interfere with their modus operandi

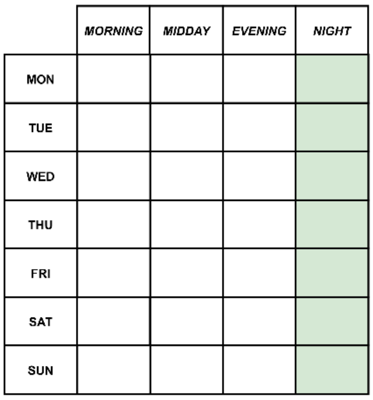

Figure 5-117 G2 (example)

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G3. Contingent: A configuration that reflects a TPT locations that become available under more ad-hoc and opportunistic circumstances. Although most candidate sites from the analysis fall into one of the two first patterns, a small subset may exhibit irregular or opportunistic availability. An example is construction sites near the water (or construction material providers and contractors delivering the supplies to such sites), which may need waterborne transport services for a specific period of time as the construction progresses. An adjacent example is the potential delivery of parts for factory maintenance and/or repairs, or seasonal, event-driven or one-off deliveries of goods and commodities. Thus, this configuration works at sites that cannot offer sustained TPT services, whether *Continues* or *Constrained* to regular timeslots. In theory, all of the identified sites of the analysis would be able to accommodate a *Contingent* temporal availability configuration.

	MORNING	MIDDAY	EVENING	NIGHT
MON				
TUE			!	!
WED				
THU			!	!
FRI				
SAT	!	!		
SUN	!	!		

Figure 5-118 G3 (example)

Thus, three temporal availability configurations have been defined that determine when (and, thus, how) a TPT can operate. Continuous availability mirrors traditional terminal operations where round-the-clock operations are enabled within industrial settings. Constrained availability aligns TPT operations with site opening hours, noise restrictions, and/or public-access considerations, and thus offer predictable but limited operational windows. Contingent availability supports ad-hoc or event-driven logistics needs and provide flexibility where sustained operations are unnecessary. Together, these configurations demonstrate how temporal alignment is essential for integrating TPTs into heterogeneous environments, ensuring that transhipment activities complement rather than conflict with surrounding land uses and operational rhythms.

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5.4.3.8. H. OPERATING MODEL

The TPT operating model refers to how the TPT is organizationally (and commercially) embedded within the logistics context which it inhabits and defines how the various responsibilities (and liabilities) for investments and operations are distributed amongst involved actors. As was identified across the sites in the analysis, the potential managerial structures would differ significantly across sites depending on whether the TPT serves an independent, integrated, or ecosystemic business need. Thus, these precise operating models were configured.

H1. Independent: A configuration that applies when the TPT functions as a stand-alone entity/operation with its own equipment and operational logic. This is typically deployed at unutilised quays or brownfields where no dominant tenant or incumbent logistics activity exists. This configuration might e. g., come from a transport operator who has identified a market opportunity in an area and want to establish a quick, modular terminal concept to test whether volumes are present. Such a constellation could for instance be seen in areas where such transport operator can have access to both transhipment and quayside storage, erecting a "classic" inland terminal in a temporary format to test market hypotheses. It may, of course, also be erected by other actors that see potential revenue in a particular TPT constellation at a particular site. Thus, the independent operating model mimics how most inland terminal operate today: as independent entities offering transhipment services at a given location.

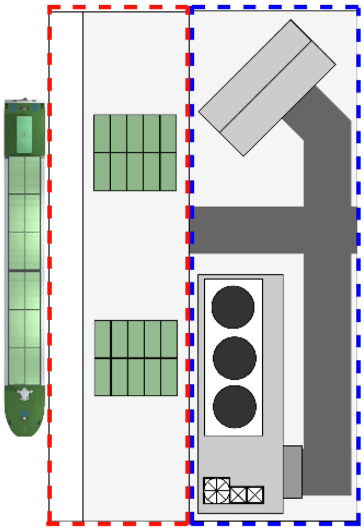

Figure 5-119 H1

H2. Integrated: A configuration that applies when the TPT is embedded within a host site's existing operations (e. g. a logistics centre or a manufacturing plant) and leverages the site's infrastructure, internal circulation, and potentially even equipment or labour, requiring coordination to fit within the host's operational rhythms. Continuing on the transport operator example from F1, this constellation could be seen in areas where the transport operator is already present, e. g. via a distribution centre, and needs a low-commitment trial for testing if inland waterway transport provides increased value to existing services. In this way, the TPT becomes an integrated part of the larger logistics of the transport operator in question. The integrated configuration does not necessarily require that the transport operator's site is located immediately next to the waterway: an example could be a *remote storage* solution (using the operator's own distribution centre) with a *constrained temporal availability* (to a third-party site) which would allow the transport operator to erect an *integrated* TPT for use in weekends.

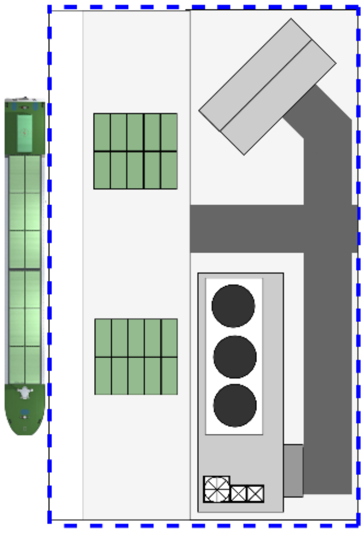

Figure 5-120 H2

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H3. Ecosystem: A configuration that emerges in areas where multiple small or mid-sized shippers, depots, or industrial actors collectively form a catchment cluster that benefits from a shared transshipment interface. Here, the TPT acts as a multi-user node that relies on distributed storage, shared access arrangements, and coordinated truck flows among several stakeholders. While the notion of *ecosystem storage* has already been mentioned, seeing the space of each ecosystem actor's premises as their own storage area, the *ecosystem operating model* addresses the governance aspects of the TPT, i.e. whether the TPT itself is operated by or in favour of the industrial ecosystem. Said differently, *Ecosystem cargo storage* is about where cargo is buffered (i.e. through a distributed network of storage areas) and *Ecosystem operating model* is about who participates and how they coordinate (i.e. how actors align on TPT operations, cost-and-revenue-sharing, service levels etc.). Either can exist without the other. For example, a site can have an *ecosystem operating model* with a single *on-quay storage configuration*, whereas another site can have an *ecosystem cargo storage* configuration with an *independent operating model*.

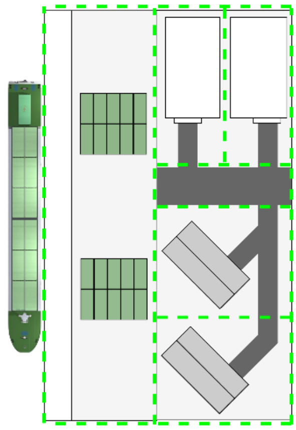

Figure 5-121

5.5 POTENTIAL TPT CONSTELLATIONS (EXAMPLES)

The TPT concept has purposefully been developed to be highly modular so that specific TPT constellations can be put together in a highly flexible and adaptable manner to serve the specific physical, operational, commercial and social needs of the context into which it will be deployed. Consequently, a total of six building blocks with various sub-block configurations allow for a mathematical total of 1.296 possible TPT constellations. While it is beyond the scope of this report to comment on all such possibilities, a few exemplary constellations will be mentioned below to clarify the modularity of the concept.

5.5.1. THE LEAN URBAN TPT

Urban waterfronts, some of which may have transitioned from former industrial spaces into mixed-use public environments, present some of the most challenging conditions for waterborne transshipment. These quays are often narrow, structurally uncertain, and highly exposed to continuous flows of pedestrians, cyclists, and recreational users. Physical and social constraints prevent the installation of industrial-grade facilities, limit operational hours and necessitate a minimal spatial footprint. Freight flows tend to be low-volume, perhaps seasonally fluctuating, and opportunistic in nature, such as those linked to construction projects, holiday deliveries, or event-based logistics initiatives. As such, a TPT deployed in such context must operate in brief windows of feasibility without compromising the surrounding public areas, making adaptability, discretion, and minimal infrastructural dependency as its central characteristics.

In this urban setting, a potential TPT configuration could be centred on water-based capabilities. In this example, cargo handling is undertaken through afloat, fixed (A3) thereby avoiding any requirement for robust operational space shoreside and relying instead on equipment mounted on barges or floating platforms. Because quayside land is scarce, the buffering function is fulfilled through floating cargo storage (B2), enabling temporary container accumulation without occupying public space. Site conditions typically lack lighting, power, or any controlled infrastructure, at least for transhipment purposes, meaning

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that the TPT operates under absent site utilities (C1) and restricts its activity to natural daylight and require mobile energy support onboard the handling/storage barges themselves. The waterside interface is kept deliberately light through minimal waterborne enablement (D1), using minimal and improvised shoreside attachments as well as, potentially, dynamic positioning from shipside. Given the modest and irregular cargo flows, the hinterland connection is handled through self-service pick-up (E3), where users collect their own cargo at designated times. As the quay cannot realistically be fenced or secured, the site functions with open access (F1), relying on temporal separation from public use rather than physical barriers. This requires operations to be deployed only when circumstances allow, resulting in contingent availability (G3). The constellation is best governed as an independent TPT (H1), enabling a transport operator to mobilise the setup only when needed and without relying on an individual actor's premise nor on the broader coordination between multiple actors.

Table 5-2 Overview of the LEAN urban TPT example

Building Block	Configurations (examples)
A. Cargo Handling	A3. Afloat, fixed cargo handling
B. Cargo Storage	B2. Floating cargo storage
C. Site Utilities	C1. Absent site utilities
D. Waterway Interface	D1. Minimal enablement
E. Hinterland Interface	E3. Self-service pick-up
F. Public Interface	F1. Open access
G. Temporal Availability	G3. Contingent availability
H. Operating Model	H1. Independent TPT

5.5.2. INDUSTRIAL-CLUSTER GATEWAY TPT

Industrial clusters typically consist of multiple small-to-mid-sized firms with heterogeneous and modest transport needs in isolation, but potentially with significant transport volumes when bundled. While no single firm can justify dedicated inland terminal infrastructure, the spatial concentration of industrial activities creates latent demand for a shared terminal node through which inland waterway transport can be enabled. Waterfronts in these areas are often functionally workable, sometimes even with legacy quay features, but not fully serviced. Furthermore, they are often embedded within dense internal traffic systems where shift patterns amongst the many industrial actors and the consequent traffic congestion shape the temporal windows for feasible operations for the TPT. Partial fencing is common, but full perimeter control rarely exists – at least not for the industrial estate at large. This context therefore requires a TPT constellation that is robust yet adaptable, able to coordinate between several stakeholders, and capable of complementing rather than disrupting the industrial rhythm of the cluster.

Within this cluster setting, a potential TPT configuration could use ashore, mobile cargo handling (A1), enabling efficient container transfers via reach stackers or similar mobile equipment suited for multi-user environments because the reach stacker can serve more purposes than merely transhipment. Storage functions depend on spatial availability and user arrangements but would depend on ecosystem cargo storage (B4) distributed across the sites of the participating industrial actors. To support operations beyond daylight hours without major investments, the TPT employs temporary site utilities (C2), such as portable lighting and modular power systems. Because quay geometry may be irregular or obstructed, vessel access is optimised through waterside enablement (D3), using spud barges to secure the vessel even where the quay is inadequately dimensioned. The onward movement of the cargo is handled

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through direct delivery (E2) where the participating industrial actors represent the final customer of the transport service. Public exposure remains moderate at the industrial site in general, so the site adopts limited access (F2), relying on lightweight fencing or barriers to prevent accidental intrusion during operations. Activity aligns with off-peak cluster patterns, resulting in constrained availability (G2), often focused on night-time or weekend operation windows. Since the TPT serves multiple firms and depends on their coordinated participation, governance follows an ecosystem TPT model, ensuring shared responsibilities, cost structures, and operational planning (H3).

Building Block	Configuration (examples)
I. Cargo Handling	A1. Ashore, mobile cargo handling
J. Cargo Storage	B4. Ecosystem cargo storage
K. Public Accessibility	C2. Temporary site utilities
L. Site Utilities	D3. Waterside enablement
M. Temporal Availability	E2. Direct delivery
N. Operating Model	F2. Limited access
O. Waterborne Interface	G2. Constrained availability
P. Hinterland Interface	H3. Ecosystem TPT

5.5.3. SUPPLY CHAIN INTEGRATED TPT

Controlled industrial facilities such as large manufacturing plants or logistics centres offer the most conducive environment for a deeply embedded TPT. Here, the quay, storage areas, and utility infrastructure are already part of a unified operational system with well-defined safety protocols, predictable shift structures, and, potentially, continuous industrial activity. Such sites often possess structurally robust quay surfaces, ample hard-standing areas, and secure perimeters that fully exclude public access. In these environments, the key challenge is not enabling transshipment, but optimising its integration into the host facility's existing logistics flows and production cycles without the host relying on extensive investments.

In this integrated industrial context, a potential TPT could apply ashore, fixed cargo handling (A2), drawing on the site's existing cranes or permanently mounted lifting systems that provide high efficiency and reliability. Cargo buffering remains close to the quay through on-quay cargo storage (B1), enabling tight coordination between vessel unloading, internal logistics, and production flows. The facility's robust technical environment naturally supports permanent site utilities (C3), ensuring continuous power, lighting, and operational conditions. As the quay is fully designed for routine ship calls, the transshipment interface uses shoreside enablement (D2), allowing secure and efficient mooring to enable fast and seamless transhipments. The transport service is deemed to be completed when they are transhipped to the site and directly transferred into the supply chain via direct delivery (E2), eliminating last-mile components entirely. The industrial site's established security perimeter enforces restricted access (F3), ensuring that only authorised personnel and vehicles can enter. Because the facility operates in multiple shifts, the TPT enjoys continuous availability (G1), allowing maximum scheduling flexibility. In this constellation, governance is structured as an Integrated TPT (H2), embedding the terminal operationally within the host facility's logistics system while maintaining clear coordination mechanisms between the transport operator and the industrial actor.

Building Block	Configuration
A. Cargo Handling	A2. Ashore, fixed cargo handling
B. Cargo Storage	B1. On-quay cargo storage

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C. Public Accessibility	C3. Permanent site utilities
D. Site Utilities	D3. Waterside enablement
E. Temporal Availability	E1. Last-mile delivery
F. Operating Model	F2. Limited access
G. Waterborne Interface	G2. Constrained availability
H. Hinterland Interface	H2. Integrated TPT

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6 STOW&CHARGE

6.1 INTRODUCTION

Ports and terminals as energy providers have been investigated in previous projects. The MAGPIE project has investigated supply and use of green energy carriers for port-related transport and developed a plan for European green ports. The project demonstrated electric trucking with automatic connection of charging, intension sharing for autonomous ships based on an electric barge, and ammonia bunkering between two vessels.

The Pioneers project aims at reducing the port total environmental footprint, deploying sustainable port infrastructure, introducing eco-friendly improvements, and developing a plan for transition to GHG-neutral shipping. The project has several demonstrations, including energy generation from water currents, battery storage and smart management of green energy for terminal operators, modular docking stations for energy containers, and electric last-mile for on-site logistics.

A strategy document for ports as clean energy hubs has also been published by C40, a global network of mayors driving the future of city climate action [15]

6.2 METHODOLOGY

Research design/approach:

- First, desk research was conducted to map out the potential renewable energy solutions that the Stow&Charge Hub concept could utilise as building blocks in a combined cargo and energy logistics hub. This includes:
    - Solar-derived renewable energy solutions (PV panels etc.)
    - Wind-derived renewable energy solutions
    - ZES-related energy solutions (charging station and battery containers)
- Second, a hierarchical Stow&Charge Hub concept was developed based on collaboration with DFDS Ghent and DFDS Vlaardingen green terminal developments.
- Third, potential Stow&Charge locations were examined vis-a-vis the analysis in Chapter 4 and the identified areas with renewable energy sources.
- Fourth, recommendations for where to strategically place Stow&Charge Hubs were proposed.

Methods:

- Desk research: used to map out potential renewable energy solutions for the Stow&Charge Hub concept
- Interviews: multiple, recurring un- and semi-structured interviews (i.e. somewhat close to workshops) were conducted with relevant terminal management and personnel to understand potential development pathways for green terminals

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- Workshops: multiple, recurring internal workshops in the AUTOFLEX consortium (both physically, e.g. in Duisburg, and online weekly meetings) were conducted.

6.3 POTENTIAL RENEWABLE ENERGY SOLUTIONS FOR INLAND TERMINALS

The integration of renewable energy systems into Stow&Charge Hubs (SCH) represents a central technological pathway for enabling climate-neutral energy supply in future logistics and mobility infrastructures. In this context, solar energy based on photovoltaic (PV) systems and wind energy technologies constitute the two most relevant and complementary sources for decentralized, scalable, and emission-free electricity generation. Their combined application allows for the mitigation of temporal and seasonal fluctuations in power generation while enhancing overall system resilience and supply security.

It is worth noting that other potential renewable energy solutions exist, including, but not limited to, technologies that harvest energy from tidal and/or wave energy, from geothermal energy, from hydrogen production, from biomass and bioenergy, from hydrokinetic energy through rivers and/or estuary currents, from water-to-energy (WTE) systems and many more. However, given that inland terminals operate under different constraints than large seaports, including limited spaces, tighter budgets, smaller energy loads and often lower technical capacities, many of these solutions remain simply too capital-intensive or unsuitable for inland environments. It is therefore irrelevant to study the majority of these renewable energy solutions in the context of the SCH concept development.

The following section will focus on the technical, economic, and site-specific suitability of photovoltaic and wind energy systems for SCH applications, considering their performance characteristics, structural integration requirements, and operational boundary conditions. The objective is to provide a scientifically sound basis for the optimal design and dimensioning of renewable energy supply concepts for high-power charging and energy buffering infrastructures. Said differently, it is to understand the two main building blocks of the Stow&Charge concept.

While the development of the Temporary Port Terminal (TPT) concept started by investigating potential transhipment locations within the Modal Shift Candidate Clusters to identify common denominators and preconditions of establishing transhipment operations across the sites and subsequently use these to develop the building blocks of the TPT concept, the SCH concept will be developed by first investigating potential renewable energy solutions a priori, some of which however are inspired by the use case area itself. Subsequently, these renewable energy solutions and associated variables/parameters will be used to identify *how* the modular SCH concept should be configured. Finally, in the end, the AUTOFLEX use case areas would be investigated with regards to *where* the SCH should be placed. Therefore, this chapter on the SCH may read somewhat in the opposite direction when compared to the chapter on the TPT.

6.3.1. SOLAR ENERGY SOLUTIONS (PHOTOVOLTAIC)

For the integration of solar energy into inland terminals in general, and into the Stow&Charge Hub (SCH) in particular, by means of photovoltaic modules, a wide range of system configurations and structural implementation variants is available. These include building-integrated photovoltaic (BIPV) systems, such as roof-mounted and facade-integrated PV installations, as well as canopy- and carport-based PV structures, which enable the combined

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use of surface areas for weather protection and electricity generation. In addition, ground-mounted and floating PV solutions represent further technically viable options for site-specific deployment.

Table 6-1 comprises the performed analysis, which shows, that photovoltaic systems on roofs and open areas currently represent the most economical and technically feasible option for renewable energy generation in major port areas. Large-scale rooftop installations on warehouses and handling facilities – such as those at Verbrugge Terminals in the North Sea Port (Vlissingen/Terneuzen) – provide installed capacities of up to 50 MWp and generate more than 20 GWh per year [16]. Investment costs typically range from 900 to 1.600 €/kWp, while operating costs are rather small with about 1–2% of CAPEX (approx. 10–25 €/kWp·a) [17]. In the Port of Antwerp, decentralised PV solutions with an overall installed capacity with more than 1 MWp, offer an annual CO_2 reduction of approx. 220 tons. Cost structures align with industrial rooftop benchmarks, reinforcing economic viability [18]. But also ground-mounted PV solutions such as the solar park in Zonneberg or in Ghent, comprising 55.000 modules over 22 ha with an installed capacity of roughly 15 MWp enable the possibility of renewable energy production of up to 10 GWh·a [19]. Additional potential exists in solar carports. Carports allow dual-use of parking areas (energy + weather protection) with typical system sizes between 40 and 200 kWp per module array and specific yields of 950–1,100 kWh/kWp·a. Investment costs often range from 995–1,500 €/kWp, and operating costs amount to only about 1–2% of the investment [20]. Floating PV systems are still in the market phase and achieve similar specific yields, but at somewhat higher costs [21].

The average energy yield of PV systems in Belgium is 1,050–1,100 kWh/kWp·a, making them particularly suitable for coastal locations with good solar irradiance [22]. Large-scale projects implemented in ports such as Ghent and Antwerp demonstrate solid potential for CO_2 reduction and increased energy self-sufficiency. Due to their large areas, existing grid connections, and industrial use, port areas are ideally suited for large-scale PV projects. The most technically and economically viable strategy for the future energy supply of ports lies in combining rooftop, ground-mounted, and floating PV systems, coupled with storage and charging infrastructure. The pictures [23], [18], [24], [25] illustrate representative examples of these different photovoltaic integration concepts.

Table 6-1: Overview of PV solutions in ports (examples, yields, costs)

System type	Example (location)	Installed capacity	Sources
Rooftop PV on warehouses	Verbrugge Terminals, North Sea Port (Vlissingen/Terneuzen)	50 MWp (140,000+ modules)	[16]
Rooftop PV (individual installation in Port of Antwerp-Bruges)	MSC MedRepair, Port of Antwerp-Bruges	1,080 kWp (2736 modules)	[18]
Ground-mounted PV on conversion/brownfield areas	“Zonneberg/Terranova”, Ghent (North Sea Port)	15 MWp (55,000 modules)	[19]
Solar carports (parking areas in ports/logistics)	Reference values (BeNeLux/DACH)	40–120 kWp per field (scalable)	[20]
Floating PV (basins/harbour basins)	European references (state of the art)	project-dependent (MW scale)	[26]

Types of Photovoltaic

Photovoltaic modules can be classified into several fundamental technology types based on their cell structure and material systems (see Table 6-2). These technologies differ significantly with respect to conversion efficiency, manufacturing complexity, cost structure, temperature

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behaviour, and architectural applicability. Currently, monocrystalline silicon modules represent the most widely adopted photovoltaic technology. They are manufactured from single-crystal silicon wafers with a highly homogeneous crystal lattice, which enables high conversion efficiencies typically exceeding 20 percent. Characteristically, the cells exhibit a uniformly dark to black appearance. Owing to their high-power density, monocrystalline modules are particularly suited for applications with limited available installation area. In contrast, polycrystalline silicon modules consist of multi-crystalline silicon, in which multiple crystal grains are present within each cell. This results in a lower degree of crystallographic homogeneity and consequently slightly reduced conversion efficiencies in the range of approximately 16 to 19 percent. Polycrystalline cells are visually distinguished by their bluish, grain-like crystal structure. Due to their less complex manufacturing process, they were historically more cost-effective but have increasingly been displaced from the market by monocrystalline technologies.

Another major category is thin-film photovoltaic modules, in which the photoactive semiconductor layer is deposited with very small thickness onto a substrate such as glass, metal, or polymer materials. The most relevant thin-film technologies include amorphous silicon, cadmium telluride, and copper indium di-selenide-based systems. Thin-film modules are characterized by favourable low-light performance, low temperature coefficients, and high flexibility with respect to form and weight. However, their power conversion efficiencies remain lower than those of crystalline silicon modules. Within the thin-film category, CISG modules based on copper, indium, gallium, and selenium represent a particularly advanced variant, as they achieve comparatively high efficiencies of up to approximately 18 percent. These modules combine low temperature sensitivity with relatively high area efficiency and are therefore increasingly applied in building-integrated photovoltaic (BIPV) systems.

A special class of photovoltaic products is represented by semi-transparent PV modules, which are designed to integrate light transmission with electrical power generation. These modules may be based on both crystalline silicon technologies with defined cell spacing and thin-film systems with controllable optical transmittance of the active layer. Semi-transparent modules enable the dual use of building envelope elements as daylight-transmitting components and energy-generating surfaces. Typical applications include building facades, overhead glazing, atria, and conservatories. By adjusting the degree of transparency, both light transmission and shading characteristics as well as the electrical energy yield can be specifically tailored to architectural and energetic requirements.

In summary, the different photovoltaic module technologies differ substantially in terms of efficiency, material consumption, temperature behaviour, economic performance, and integration potential. While monocrystalline silicon modules currently define the state of the art for maximum power density, thin-film, CISG, and semi-transparent photovoltaic systems offer distinct advantages in specialized applications such as facade integration, lightweight constructions, and daylight-transmitting building structures.

Table 6-2: Overview of current PV module technologies and application areas

Module technology	**Description / cell type**	**Typical efficiency (%)**	**Power density (Wp/m²)**	**Advantages**	**Application areas**	**Price (€/Wp)**	**Sources (2024–2025)**
Monocrystalline PERC (mono-Si, bifacial)	p-type with rear-side passivation;	19–22% (+5–15% bifacial gain)	190–210	High availability, good cost-performance,	Rooftop/ground-mount, industrial/port areas	$0.081-0.088	[27] [25]

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	optional bifacial			proven in large plants			
Polycrystalline (p-Si)	p-type with multiple crystallites	16–18%	160–180	Low cost, robust, proven technology	Older roofs, small commercial areas	0.07–0.10	[26] [27]
n-Type / TOPCon (bifacial)	n-doped with tunnel oxide and polysilicon contact	21–24% (up to 26% lab)	200–220	Low degradation, strong temperature performance	Large plants, floating PV, maritime climates	0.10–0.13	[31] [32]
Heterojunction (HJT)	c-Si + amorphous Si	22–25%	210–230	Very high efficiency, low degradation, good performance in diffuse light	Premium, floating, facades	0.13–0.16	[27] [33]
Thin-film (CdTe, CIGS)	Thin active layer	10–20%	100–160	Good for diffuse light, lightweight, flexible formats	Facades, lightweight structures	0.08–0.11	[34] [33]
Agri-PV	Semi-transparent	16–21%	120–180	Dual use of spaces, controllable light transmission	Port edge zones, logistics areas	0.12–0.18	[34] [37]
BIPV (facade/roof integration)	Building-integrated	15–22%	120–200	Dual function: building envelope + energy generation, aesthetic integration	Terminals, offices, facade systems	0.8–1.6	[36] [37]

Mounting systems

Photovoltaic mounting and support systems constitute a key structural and functional component of solar energy installations, as they directly influence system durability, safety, energy yield, and economic performance. Depending on the application environment and load conditions, photovoltaic mounting solutions can be broadly classified into ground-mounted systems, roof- and facade-mounted systems, and floating photovoltaic (FPV) systems [40] (see Table 6-3).

Ground-mounted mounting systems are primarily deployed in open-field solar power plants and large-scale utility installations. These systems typically consist of steel or aluminium racking structures that are either pile-driven, screw-anchored, or installed on concrete foundations. Ground-mounted systems enable optimal module orientation with respect to tilt angle and azimuth, thereby maximizing annual energy yield. In addition, they allow for flexible layout configurations and ease of maintenance. Depending on the project requirements, both fixed-tilt structures and single- or dual-axis tracking systems are applied. While fixed systems offer high structural simplicity and reliability, tracking systems provide increased energy yield at the expense of higher mechanical complexity and investment costs. The structural design of ground-mounted systems must account for site-specific wind, snow, and seismic loads as well as soil bearing capacity and corrosion conditions [41].

Roof- and facade-mounted photovoltaic systems represent the dominant solution for building-integrated and building-attached photovoltaic applications. On pitched roofs, mounting systems typically consist of rail-based structures mechanically fixed to roof rafters using roof hooks, brackets, or anchoring screws. Flat-roof installations frequently employ ballasted mounting systems, which rely on weighted support frames without roof

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penetration, thereby minimizing risks related to waterproofing and structural damage. Facade-mounted PV systems require specialized fixing solutions that accommodate vertical load transfer, thermal expansion, wind suction forces, and aesthetic integration. These systems are commonly realized using rear-ventilated substructures based on aluminium profiles, point-fixation systems, or curtain wall-integrated PV elements. Roof- and facade-mounted systems must be carefully engineered to ensure structural safety, weather resistance, fire protection compliance, and long-term durability under cyclic mechanical and thermal loading [42].

Floating photovoltaic systems, also referred to as floating PV (FPV), represent a rapidly growing application field, particularly on artificial water bodies such as reservoirs, gravel pits, and cooling ponds. FPV systems are based on buoyant polymer pontoon structures that support PV modules above the water surface. The entire system is stabilized through a combination of mooring lines, anchoring systems, and flexible couplings that compensate for water level fluctuations and hydrodynamic loads. Floating PV installations offer significant advantages, including reduced land use, improved module cooling due to evaporative effects, and enhanced system efficiency. However, FPV systems impose increased requirements on material resistance against moisture, ultraviolet radiation, biofouling, and corrosion. The mechanical design must further account for wave loads, wind-induced oscillations, and fatigue effects in anchoring components [43].

In summary, photovoltaic mounting and fastening systems are highly application-specific engineering solutions that must be tailored to environmental conditions, structural interfaces, load cases, and system performance requirements. While ground-mounted systems provide maximum flexibility and scalability for large solar power plants, rooftop and facade systems enable efficient use of building surfaces for decentralized energy generation. Floating photovoltaic systems, in turn, represent an innovative solution for land-efficient solar deployment with distinct thermal and mechanical boundary conditions. The appropriate selection and structural design of the mounting system are therefore decisive for the long-term technical and economic performance of photovoltaic installations.

Table 6-3: Overview of current PV module mounting systems

System type	Description / application	Advantages	Challenges	Typical variants / examples
Fixed-tilt ground mounts	Fixed angle (15–35°), mounted on posts or racks	Low-cost, robust, low maintenance	No tracking → lower yield per area	Aluminium/steel frames, posts, rail systems
Manually adjustable tilt	Seasonal angle adjustment (e. g. summer/winter)	+5–10% higher yield	Manual effort required	Pivot frames, hinge structures
Trackers (single-/dual-axis)	Modules track the sun; yield +25% possible	Highest energy yield	Higher CAPEX & maintenance	Single-/dual-axis tracker
Pile and screw foundations	Posts rammed or screwed into ground	Low concrete demand, fast installation	Soil critical, corrosion risk	Steel piles, screw foundations
Ballasted systems (non-anchored)	Modules on heavy concrete slabs/blocks	No soil penetration	High ballast mass, transport effort	Concrete frames, heavy slabs
Carport and canopy structures	Above parking/logistics areas	Dual use of space, Charging integration	Higher static & safety requirements	Steel frames, beams, post systems
Floating systems	Modules mounted on pontoons or plastic supports on water surfaces	Space-saving, cooling effect, high efficiency	Waves, corrosion, anchoring	Pontoons, modular floating platforms

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BIPV facades	Photovoltaic integration into facades, curtain wall or thermally integrated elements	Dual function: building envelope + power generation; high architectural integration	Higher cost, complex installation	-Glass-glass PV elements as a ventilated curtain wall

In summary, photovoltaic mounting systems for inland waterway commercial applications require integrated structural, hydrodynamic, and corrosion-resistant design concepts. While ground-mounted systems provide robust solutions for logistics yards and flood-secure areas, rooftop and facade systems enable efficient exploitation of existing building envelopes. Floating PV installations, in turn, offer a highly attractive expansion option for land-scarce industrial waterway sites. The appropriate selection and engineering design of the mounting system are therefore decisive for long-term operational reliability, electrical performance, and economic efficiency under inland waterway conditions.

The mounting system typically represents approximately 10-25% of the total photovoltaic system investment, depending on site conditions, soil characteristics, and structural design [44]. In port and inland waterway environments, the use of corrosion-resistant materials such as aluminium, stainless steel, and hot-dip galvanized steel is considered standard practice. These materials generally increase CAPEX by approximately 10-15%; however, they significantly reduce long-term maintenance requirements and substantially extend the service life of the overall system [45].

OPEX for fixed mounting systems are generally low and are typically restricted to periodic visual inspections and preventive corrosion protection measures. In contrast, tracking systems and floating photovoltaic installations exhibit higher OPEX due to the presence of moving components, bearings, and anchoring systems. In such cases, annual operating costs typically range between 1.5 and 3% of the initial CAPEX, whereas rigid fixed systems usually remain below 1% per year [46].

Challenging subsoil conditions, such as soft or contaminated soils, favour the application of ballasted foundations or ground screw systems, whereas floating photovoltaic installations require ultraviolet-resistant and mechanically flexible mooring solutions. In general, higher initial investments in corrosion-resistant and low-maintenance structural designs result in enhanced operational reliability and significantly prolonged service life of the photovoltaic system as a whole.

6.3.2. WIND ENERGY SOLUTIONS

Wind energy represents one of the most mature and rapidly expanding renewable energy technologies worldwide and is a central pillar of the global energy transition. Wind turbines convert the kinetic energy of the wind into electrical energy through aerodynamic rotor blades connected to an electromechanical generator. Depending on their installation environment, wind energy systems are fundamentally categorized into onshore and offshore wind turbines, which differ significantly in terms of structural design, investment requirements, operational conditions, and energy yield potential.

Offshore wind turbines

Offshore wind turbines are deployed in marine environments, primarily in coastal and deep-sea regions. These systems benefit from higher and more stable wind speeds, resulting in significantly higher capacity factors and energy yields compared to onshore installations. Offshore wind turbines require complex foundation solutions such as monopile, jacket,

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gravity-based, or floating substructures, depending on water depth and geotechnical conditions. Due to harsh environmental loads, including waves, currents, saltwater corrosion, and limited accessibility, offshore systems involve substantially higher capital and operational expenditures but deliver superior long-term energy production.

An image illustrating possible foundation solutions that are being used for offshore wind turbines can be found here [47]. Key factors for the selection of the most eligible foundation are the water depth, dynamic load distributions, weight of the turbine and tower section and seabed characteristics. All foundation types for coastal wind turbines are installed using piled steel tubes up to 35 m long driven into the seabed. The following Table 6-4 comprises characteristics for the different foundation systems.

Table 6-4: Characteristics of deep sea and coastal foundation solutions

System	Typical water depth	Description / deployment
Monopile (fixed foundation)	~10–40 m (up to ~60 m in recent projects)	Large-diam. steel pile, driven into the seabed; standard for nearshore sites in Europe; highly mature and widely deployed. [48]
Jacket (lattice frame)	~30–80 m	Three-/four-legged steel lattice supporting deeper, rougher sites; higher stiffness, more complex manufacturing/installation. [48]
Gravity base	~5–40 m	Concrete foundation using its own weight for stability; used in very nearshore locations with suitable sediment. [49]
Floating (Spar / Semi-Sub / TLP)	>~60 m	Floating concepts with mooring systems; allow development of deep or exposed sites. Floating concepts with mooring systems; allow development of deep or exposed sites. [50]

Offshore wind turbines represent the most powerful class of wind energy converters and are specifically designed for large-scale electricity generation under harsh marine conditions. State-of-the-art offshore wind turbines currently exhibit rated power levels typically ranging from 6 to 15 MW per unit [51], with next-generation prototypes exceeding 20 MW [52]. This rapid increase in unit capacity is primarily enabled by continuously growing rotor diam., which today commonly range between 180 and 240 m, with corresponding swept areas of more than 30,000 m² [53]. Large rotor dimensions allow efficient energy harvesting at lower wind speeds and significantly increase annual energy yield and capacity factors, which typically range between 45% and 60% in offshore environments [54].

The economic performance of offshore wind energy is dominated by high capital investment requirements. Typical CAPEX for offshore wind farms currently ranges between approximately 4,000 and 4,500 EUR/kW, depending on water depth, foundation type, distance to shore, grid connection concept, and installation logistics [55]. The main CAPEX components include turbine procurement, foundations and substructures, offshore installation, electrical infrastructure, and grid interconnection.

OPEX are substantially higher than for onshore wind systems due to limited accessibility, offshore logistics, and increased mechanical and corrosion-related stresses. Typical OPEX values amount to approximately 2.5–4.5% of CAPEX per year, covering condition monitoring, preventive and corrective maintenance, service vessels, offshore cranes, and spare parts logistics [56]. Despite higher OPEX, offshore wind farms benefit from superior wind conditions, resulting in high full-load hours and favourable long-term energy yields.

The following tables comprise an overview of current medium and large offshore wind turbines.

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Table 6-5: Characteristics of medium-sized offshore wind turbines state of the art

Manufacturer / Model	Rated Power	Rotor Ø	Remarks	Source
Goldwind GW184-6.45 MW	6.45 MW	184 m	Offshore turbine with large rotor for higher energy yield (~ 25 GWh/a at CF ≈ 45 %).	[59]
Vestas V162-6.8 MW (EnVentus)	6.8 MW	162 m	Designed for near-shore and shallow-water sites; CF ≈ 40–45 %, AEP ≈ 24 GWh/a.	[60]
Siemens Gamesa SG 7.0-170	7.0 MW	170 m	Proven platform for coastal locations; AEP ≈ 26 GWh/a.	[61]

Table 6-6: Characteristics of large-sized offshore wind turbines state of the art

Manufacturer / Model	Rated Power	Rotor Ø	Remarks	Source
Vestas V236-15.0 MW	15 MW	236 m	Manufacturer quotes up to ≈ 80 GWh/a AEP (site-specific, CF ≈ 55–60 %).	[62] [61]
Siemens Gamesa SG 14-236 DD	14 MW	236 m	115 m blade length, 43 500 m² rotor area, AEP ≈ 75 GWh/a.	[64] [65]
GE Haliade-X 14.7 MW	14.7 MW	220 m	Deployed e. g. at Dogger Bank; AEP ≈ 70 GWh/a.	[66] [67] [66]

In summary, offshore wind turbines combine very high unit capacities, extremely large rotor systems, and superior energy yield potential, at the expense of elevated investment and operational costs. Their large-scale power output and high-capacity factors make offshore wind energy a cornerstone technology for future climate-neutral electricity systems.

Onshore wind turbines

Onshore wind turbines are installed on land-based sites such as open plains, ridgelines, and industrial areas. They are characterized by comparatively lower investment and operating costs, well-established erection and maintenance procedures, and high flexibility with regard to site selection. Typical hub heights and rotor diameter have continuously increased over recent decades in order to access higher wind speeds and improve energy yield. Onshore systems are particularly suitable for decentralized power generation and integration into regional electricity grids.

Onshore wind turbines represent the most widely deployed and economically mature segment of wind energy conversion systems and play a central role in decentralized and large-scale electricity generation. Continuous technological development over recent decades have led to a significant increase in unit ratings, rotor dimensions, and overall energy yield. State-of-the-art onshore wind turbines currently exhibit rated power outputs typically ranging from 3 to 7 MW per unit, while next-generation turbines increasingly approach 8 to 10 MW. This performance increase is closely linked to expanding rotor diameter, which today commonly range between 120 and 180 m, resulting in swept areas exceeding 25,000 m² [67]. Enlarged rotors enable enhanced energy capture at moderate wind speeds and contribute to improved annual energy yields and capacity factors, which typically range between 25% and 40%, depending on site-specific wind conditions [55].

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From an economic perspective, onshore wind energy is characterized by comparatively low capital investment requirements relative to offshore installations. Typical CAPEX for modern onshore wind projects currently ranges between approximately 1,300 and 1,900 EUR/kW, depending on turbine size, site accessibility, grid connection distance, foundation type, and local permitting conditions. The main CAPEX components include turbine procurement, civil engineering works, foundations, electrical infrastructure, and installation [68].

OPEX for onshore wind turbines remain moderate due to good site accessibility, well-established maintenance strategies, and mature supply chain structures. Annual O&M costs for onshore wind typically range between 20–60 USD/kW/year, corresponding to roughly 2–4% of total installed costs[55]. The combination of comparatively low OPEX, favourable CAPEX, and reliable long-term performance results in highly competitive levelized cost of electricity (LCOE) values for onshore wind power.

Near-coastal onshore wind turbines are structurally equivalent in their fundamental design to conventional land-based wind energy systems but benefit significantly from the superior wind conditions characteristic of coastal regions. These installations typically consist of a steel or hybrid tower structure, mounted on a reinforced concrete foundation, whose design is highly dependent on the local geotechnical conditions. In areas with stable sediments, shallow or ring foundations are commonly applied, whereas pile foundations are required in softer subsoils such as coastal marshlands, dike zones, or reclaimed land. Recent studies confirm that optimized foundation concepts with reduced material input are increasingly being developed for coastal lowland conditions [69], [70].

The site characteristics of near-coastal locations, including low surface roughness lengths, reduced turbulence intensity, and mean annual wind speeds frequently exceeding 7 m/s at 100 m hub height, provide a decisive advantage over inland locations [71]. As a result, near-coastal onshore wind turbines typically achieve higher full-load hours and capacity factors, generally in the range of 30 to 40%, whereas inland sites usually remain within 25 to 30%. These favourable wind conditions support the deployment of large-scale turbine classes, which today dominantly range between 4 and 7 MW rated power, with rotor diameter of up to approximately 180 m [71].

For modern near-coastal installations, annual energy production (AEP) typically reaches 10–13 GWh/a for 4 MW turbines, 12–15 GWh/a for 5 MW turbines, 14–18 GWh/a for 6 MW turbines, and 15–20 GWh/a for 7 MW turbines at high-quality coastal sites [72]. Emerging 8–10 MW turbine classes, equipped with rotor diameter of 180–200 m and above, may reach 18–25 GWh/a under very favourable coastal conditions [73]. Typical total investment costs range between 2,000 and 2,800 EUR/kW, corresponding to 8–25 million EUR per turbine, depending on size class and site conditions [68], [74]. Typical near-coastal deployment areas include dike systems, exposed coastal strips, and wind-rich coastal hinterland regions, where the combination of high wind availability and favourable terrain enables exceptional energy yields. In addition to greenfield developments, repowering plays a major and growing role, as existing grid connections and previously approved sites can be reused for significantly larger and more efficient turbines. This trend is particularly pronounced in Germany and the Netherlands.

At the global scale, total installed onshore wind capacity reached approximately 1,052 GW by the end of 2024, clearly dominating global wind power deployment [75]. In Europe, onshore capacity amounted to 248 GW, with typical turbine sizes between 3 and 6 MW and average energy yields of 8–18 GWh/a, depending on site quality [67]. The Netherlands reached 6.94

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GW of onshore wind capacity by 2024, with strong concentration in coastal provinces and typical turbine sizes of 4–7 MW, achieving 10–18 GWh/a[76]. Belgium operates approximately 3.33 GW of onshore wind, with a strong focus on harbour-adjacent industrial zones [77]. Prominent large-scale near-coastal applications include the Port of Antwerp-Bruges with approximately 200 MW of onshore wind capacity, Rotterdam harbour with about 308–330 MW, Amsterdam harbour with 75 MW, and the Port of Ghent, where ≥ 70 MW are directly documented and a total harbour capacity exceeding 100 MW can be inferred.

In summary, near-coastal onshore wind turbines represent a high-yield, structurally mature, and economically efficient wind energy segment, characterized by elevated wind speeds, large turbine dimensions, superior capacity factors, and excellent repowering potential. Their strategic role is particularly pronounced in coastal industrial zones and port-related energy hubs, where proximity to high-capacity grid infrastructure and large electricity consumers enables an optimal integration into future climate-neutral energy systems.

Table 6-7: Typical Turbine Sizes and Annual Yields for Coastal Onshore Sites

Rated Power	Typical Rotor Ø	Estimated annual yield (AEP)	Source / Status
~ 4 MW	135–145 m	10–13 GWh/a	[78], [61]
~ 5 MW	150–160 m	12–15 GWh/a	[78], [61]
~ 6 MW	160–170 m	14–18 GWh/a	[61], [79]
~ 7 MW	170–180 m	15–20 GWh/a (at good coastal sites)	[61], [80]
~ 8–10 MW	180–200 m or more	18–25 GWh/a (best coastal sites)	[80], [61]

In summary, onshore wind turbines combine moderate to high unit capacities, large rotor systems, and comparatively low investment and operating costs, making them a cornerstone of cost-effective renewable electricity generation and regional energy supply systems. Their scalability, technological maturity, and economic efficiency ensure a key role for onshore wind energy in achieving long-term climate-neutral power generation targets.

6.3.3. ZES BATTERY CONTAINERS AND CHARGING INFRASTRUCTURE FOR RENEWABLE ENERGY HUBS

The Stow&Charge Hub (SCH) concept is based on the integration of cargo handling, energy supply and digital coordination at inland terminals. Renewable energy is not only an additional feature but a central component of the overall transport concept. By combining modular battery systems with dedicated charging infrastructure, it becomes possible to operate inland vessels in a fully electric and zero-emission manner while maintaining operational flexibility.

A practical example of such an approach is provided by ZES [81]. The ZES ecosystem combines exchangeable battery containers and standardized charging stations. It illustrates how inland terminals can develop into energy hubs that connect shipping operations with renewable electricity supply and grid services.

ZESpacks – Modular and swappable Energy Containers

The main technological element of the ZES system is the ZESpack. It is a modular energy container designed in the standardized 20-foot ISO container format. This ensures compatibility with existing container logistics systems and allows the battery units to be handled using conventional terminal equipment, such as reach stackers or cranes (see [82]).

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Each ZES pack provides approximately 2.6 MWh of usable energy at Beginning of Life (BoL) within the defined operational state-of-charge window. Over its service life, the usable energy capacity decreases due to battery ageing, resulting in approximately 2.0 MWh of usable energy at End of Life (EoL), see [83].

The containers are equipped with integrated safety systems, including fire suppression and gas detection. They are specifically designed for maritime use and can withstand vibrations and mechanical loads occurring during vessel operation. The concept has received Approval in Principle (AiP) from Lloyd's Register.

An important characteristic of the ZESpacks is its technological flexibility. Although it currently uses LFP (Lithium-Iron-Phosphate) battery technology, the standardized container concept allows the future integration of other energy carriers, such as hydrogen fuel cells, without fundamental changes to the vessel–terminal interface [83].

ZES Charging Stations – Infrastructure and Energy Hub Function

In addition to the modular battery containers, the ZES concept comprises dedicated **exchange and charging stations** installed at strategically selected inland terminals along relevant transport corridors. These stations constitute the physical backbone of the energy exchange system and enable a seamless integration of battery swapping and charging into routine terminal operations.

A central operational advantage of the system is the rapid exchange process combined with standardized high-power charging. The ZES charging infrastructure is based on an "open-access design" using a standardized MCS (Megawatt Charging System) connector at the interface between vessel and docking station. This standardization ensures interoperability between different vessels and charging infrastructures and supports rapid market adoption across inland shipping corridors.

When a ZESpack is depleted, there is no need to wait for onboard charging to be completed. Instead, the containerized battery can be replaced by a fully charged unit within approximately 15 minutes. This short exchange time minimizes vessel downtime and is particularly advantageous for automated inland vessels, where high operational availability and predictable turnaround times are essential. By decoupling vessel operation from the charging duration, the concept significantly increases operational flexibility.

The charging stations can recharge two ZESpacks in parallel, each at a power level of up to 1 MW. Under standard grid conditions, a full recharge can be achieved in approximately 2.5 to 3 hours, depending on grid capacity and configuration [83]. This means that while one battery is deployed on board, another can be recharged simultaneously, creating a continuous energy cycle without interrupting vessel deployment. In addition, charging processes can be scheduled during periods of lower electricity prices, which further improves the economic efficiency of the system. The infrastructure has been standardized and developed in close alignment with the battery container design to ensure compatibility, safety and high charging efficiency. The required footprint for a typical installation is approximately 15 m × 25 m, allowing integration into existing terminal layouts with limited spatial modifications.

The stations are designed as "open access" facilities. This means that, beyond charging ZESpacks, the high-power charging infrastructure can also be used for other electric transport modes, such as trucks, buses and electric-powered reach stackers. As a result, the charging sites function as multifunctional Energy Hubs, supporting the broader electrification of

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logistics chains. The shared use of high-capacity grid connections improves infrastructure utilization rates and strengthens the economic viability of the installations.

From a system perspective, the charging stations can be directly connected to sustainably generated electricity. In combination with potential stationary buffer storage, they allow flexible load management and the possibility to shift charging processes to periods with favourable electricity prices or high renewable energy availability. This contributes to both cost optimization and improved environmental performance. Furthermore, the integration with the local grid opens opportunities for ancillary services, such as peak shaving or frequency stabilization, enhancing the overall system value.

Within the AUTOFLEX Stow&Charge Hub (SCH) framework, such open-access charging stations represent critical nodal points where cargo handling and energy logistics converge. They enable structured energy module exchange, maintain high vessel availability and facilitate the development of zero-emission inland shipping corridors supported by scalable and interoperable infrastructure.

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6.4 THE STOW&CHARGE HUB (SCH) CONCEPT

6.4.1. LEVEL 0 – THE CONVENTIONAL INLAND TERMINAL (BASELINE)

From a technical perspective, the Stow&Charge Hub – Level 0 (SCH-0) represents a standard inland terminal with none to limited energy-related infrastructure. It contains only the core physical and operational assets needed for cargo handling: a quay, a terminal area and terminal equipment (often diesel-powered). Consequently, electrical systems at the SCH-0 level pertains to building loads (such as lighting, HVAC, IT etc.) and cannot in any shape or form support charging infrastructure for heavy vehicles or inland ships. SCH-0 is technically thus a pure logistics node. Thus, in terms of relevant technical architecture, the SCH-0 (baseline terminal) has:

- Cargo Handling Equipment. While this may be a trivial mentioning, it does play an important role in the SCH constellations because it is the very cargo handling equipment (such as quay cranes and reach stackers etc.) that allow the ZES battery containers to be transhipped to and from the inland ships, the terminals and the ZES charging stations. Consequently, the cargo handling equipment must be mentioned in the context of SCH-0.

Adapting the inland terminal types identified by Smid et al. [84] to fit the context of the AUTOFLEX project (see Table 6-8), we can create a breakdown of inland terminal sizes. This will be crucial in estimating the energy needs and thus the potential energy independence of these terminals.

Table 6-8: terminal types as per Smid et al. [84]

Name	Throughput (TEU/year)	Terminal Size (ha)	Shore Cranes (#)	Reach Stackers (#)
XXL terminal	500.000	15,0	3	3
XL terminal	200.000	7,0	2	3
L terminal	125.000	4,0	2	2
M terminal	50.000	3,0	1	1
S terminal	20.000	1,5	1	1
XS terminal	10.000	1,0	0	2
XXS terminal	5.000	0,5	0	1

This terminal categorization is supplemented with 17 inland terminals managed by the Inland Terminals Group in order to validate and contextualize the categorizations in a real-world setting. Do note that the "terminal category" column of Table 6-9 has been created vis-à-vis the earlier terminal categorization and that the number of reach stackers for each location has also been estimated using this terminal categorization. These 17 locations are not necessarily SCH-0 configurations. For instance, ZES reports that they have recently installed a charging station at Den Bosch, which would immediately have it classified as SCH-2 or above. Furthermore, it is well documented in research that the throughput of a terminal is not necessarily the maximum capacity of the terminal. In their statistical analysis of 44 inland container terminals in Europe, Wiegmans and Witte [85] find that the discrepancy between the throughput and the handling capacity is around 60%. Consequently, this utilization rate has been used for the 17 real-world validation cases.

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Table 6-9: Inland terminals

Location	Capacity (TEU/year)	Throughput (TEU/year)	Size (ha)	Shore cranes	Reach stackers*	Terminal category
Alblasserdam	140.000	84.000	4,8	2	2	**L**
Almelo	125.000	75.000	3,2	1	2	**L**
Beringen	60.000	36.000	3,0	1	1	**M**
Den Bosch	160.000	96.000	4,5	2	2	**L**
Deventer	30.000	18.000	1,5	1	1	**S**
Geel	70.000	42.000	3,4	1	1	**M**
Groningen	116.000	69.600	2,9	2	2	**M**
Hengelo	300.000	180.000	12,5	2	3	**XL**
Kampen	92.000	55.200	2,3	1	1	**M**
Leeuwarden	100.000	60.000	2,5	1	1	**M**
Lommel	60.000	36.000	2,0	1	1	**M**
Meerhout	400.000	240.000	13,0	3	3	**XXL**
Meppel	136.000	81.600	3,4	1	2	**L**
Nijmegen	160.000	96.000	4,0	2	2	**L**
Roermond	72.000	43.200	1,8	1	1	**M**
Rotterdam (Pernis)	100.000	60.000	8,5	3	2	**XL**
Venray-Wanssum	125.000	75.000	5,6	1	2	**L**

* As no official information is available, this is estimated based on the terminal category breakdown.

Lastly, the terminal categorization and the terminal validations are further supplemented by potential AUTOFLEX transport scenarios (see Table 6-10) using the CEMT II autonomous vessel OSCAR II, as mentioned earlier. This is necessary to contextualise the operations of the SCHs into the AUTOFLEX transport ecosystem which may not be immediately transferable to the real-life validation terminals of the Inland Terminals Group. For each AUTOFLEX scenario, the associated terminal category has been used.

Table 6-10: AUTOFLEX transport scenarios

AUTOFLEX Logistics Scenarios	Throughput (TEU/year)	Expected terminal category	Terminal Size (ha)	Shore cranes	Reach Stackers
20 daily services with OSCAR II	175.200	L	4,0	2	2
10 daily services with OSCAR II	87.600	M	3,0	1	1
Five daily services with OSCAR II	43.800	M	3,0	1	1
Three daily services with OSCAR II	26.280	S	1,5	1	1
One daily service with OSCAR II	8.760	XS	1,0	0	2
Two weekly services with OSCAR II	2.496	XXS	0,5	0	1
One weekly service with OSCAR II	1.248	XXS	0,5	0	1

From an operational perspective, the SCH-0 supports only conventional cargo flows. The terminal cannot supply renewable energy (via electricity) to neither trucks, terminal

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equipment or inland ships. However, this does not necessarily mean that electrical ships or vehicles cannot visit or work at the terminal; they will just have to rely on electric energy from external charging infrastructure outside the terminal. Thus, the terminal cannot function as an energy node, nor can it offer a competitive advantage derived from the green transition. The lack of electrification also means that the SCH-0 continues to rely heavily on heavy diesel equipment which contributes to local noise and emissions. Consequently, the SCH-0 terminal is not suitable for placement in the vicinity of residential areas or urban zones – the very use case of the AUTOFLEX project.

From a financial perspective, the SCH-0 has no financial investments vis-à-vis the SCH concept as it can hardly be considered part of the SCH hierarchy. CAPEX is limited to standard costs associated with normal terminal development and procurement, and while OPEX may remain somewhat predictable, it is severely vulnerable to fluctuations in diesel fuel prices. With regards to revenue streams, the SCH-0 only generate income from transshipment activities and cannot branch out into supporting energy-related revenue streams (i.e. selling surplus renewable energy produced at the site) as more advanced SCH constellations can. As supply chains increasingly prioritise low-emission and energy-resilient logistics networks, SCH-0 may risk becoming commercially unattractive in the near future. Furthermore, for smaller SCH-0s, the value proposition of transshipment services may not be a sufficient offset to enable the modal shift, forcing shippers to choose road-based transport solutions over waterborne transport solutions.

6.4.2. LEVEL 1 – THE BATTERY-ENABLED SCH

From a technical perspective, this is the first level of the Stow&Charge Hub (SCH) framework that introduces a renewable energy component: a containerized battery that can be used much like batteries are used in households today. That is, the Stow&Charge Hub – Level 1 (SCH-1). For the purposes of the AUTOFLEX project, the Zero-Emission Services (ZES) battery configurations will be used. Technically, the SCH-1 still depends on the broader energy ecosystem of the AUTOFLEX transport system and the circulation/distribution of ZES battery containers. This creates a modular approach to renewable energy availability similar to the existing ZES business for inland ships but extends this capability to include also terminal equipment.

The energy-demand results presented in the previous chapters form the foundation for determining how Stow&Charge hubs must be designed, dimensioned and strategically located along the AUTOFLEX operational corridors. Because zero-emission vessel operation rely entirely on ZESpacks, the ability of terminals to reliably supply, charge and store these battery units becomes a central element of the AUTOFLEX transport system. Thus, in addition to the SCH-0 architecture, the SCH-1 architecture also includes:

- One or more (ideally several) ZES battery containers that can be used as mobile charging modules for ships, terminal equipment and road vehicles.
- Necessary cabling that allows for primarily terminal equipment, but also, potentially, road vehicles, to connect to the ZES battery containers to draw energy from the units.

Given that a ZES battery container can deliver 2600 kWh (when full), the SCH-1 can be scaled modularly based on this potential energy availability. This energy should be available to the terminal's own equipment, such as reach stackers and cargo cranes. Do however note that for the purposes of the SCH-1, the last mile truck transport is not immediately expected to be serviced by the SCH-1 energetically. This does not mean that the terminal will not be able to accommodate electric trucks and other road vehicles; it means that these trucks and vehicles

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will have to rely on electric charging facilities outside of the SCH-1 terminal. In order to compute how much SCH-1s could operate fully or partly on the basis on ZES battery containers, the following inputs have been established:

- ZES battery containers energy: 2.600 kWh when full [83]
- Crane energy consumption: 6,0 kWh per cycle (based on Brzeziński et al. [86] and Budiyanto et al. [87])
- Crane handling rate: 25 cycles per hour (based on interviews cf. Kloch & Kristiansen [88]) – assuming that most cargo is 40" containers, this equals 50 TEU cycles per hour
- Reach stacker energy consumption: 65 kWh/hour in mixed duty
- Reach stacker handling rate: 20 cycles per hour – assuming that most cargo is 40" containers, this equals 40 TEU cycles per hour

Furthermore, it is assumed that if the terminal has a cargo crane, it will not use the reach stackers for unloading/offloading the ship. Instead, the crane will take the cargo off the ship and place it on the quay, and the reach stacker would then move the cargo from the quay to the storage area. However, if a terminal does *not* have a crane, the reach stackers would offload the vessel.

The following equation is used to calculate total power demand (kWh/hour)

$$P_{total} = P_{TEU} * TEU/year$$

Where:

- $P_{TEU} = energy\ needed\ to\ handle\ one\ TEU$
- $TEU/year = yearly\ throughput\ of\ terminal$

Because P_{TEU} depends on whether the terminal equipment includes cranes, the following equation can be established:

$$Crane\ terminal\ P_{TEU} = P_{Crane\ lift} + P_{Reach\ stacker\ shunt} + P_{Last\ mile\ trucking}$$

$$Reach\ stacker\ terminal\ P_{TEU} = 2 * P_{Reach\ stacker\ shunt} + P_{Last\ mile\ trucking}$$

Where:

$$P_{Crane\ lift} = \frac{6{,}0\ kwh/move}{2\ TEU/move} = 3.0\ kWh/TEU$$

$$P_{Reach\ stacker\ shunt} = \frac{65\ kWh/h}{40\ TEU/h} = 1{,}625\ kWh/TEU$$

Hence:

$$Crane\ terminal\ P_{TEU} = 3.0 + 1.625 = 4.625\ kWh/TEU$$

$$Reach\ stacker\ terminal\ P_{TEU} = 1.625 + 1.625 = 3.250\ kWh/TEU$$

Based on these to power demands, i.e. for craned terminals and non-craned terminals respectively, we can estimate a) how long a terminal can operate on a single ZES battery container, and b) how many ZES battery containers is needed to realise the terminal throughput (expressed as TEU/year, hence the energy needs are ZES/year).

Revisiting the terminal categories, the following energy calculations are made from the perspective of the SCH-1 – i.e. the terminal being energetically provisioned by ZES packs. Do note that this is based on the theoretical handling rates as defined earlier, not on the actual

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handling rates of the terminals in question. In a more realistic case, transshipment operations could be paced to maximize energy retention, thus allowing the terminal to operate for longer periods on the same ZES container, or use fewer containers than those specified below.

For the terminal classifications, this has the implications as listed in Table 6-11, and for the validation terminals, this has the implications as listed in Table 6-12.

Table 6-11: Power demand for terminal classes

Name	P_{Total} (kWh/year)	T_{ZES} (h/ZES)	N_{ZES} (ZES/year)
XXL terminal	2.312.500	3,75	890
XL terminal	925.000	5,62	356
L terminal	578.125	5,62	223
M terminal	231.250	11,24	89
S terminal	92.500	11,24	36
XS terminal	32.500	10,00	13
XXS terminal	16.250	20,00	7

Table 6-12: Power demand for the validation terminals

Name	P_{Total} (kWh/year)	T_{ZES} (h/ZES)	N_{ZES} (ZES/year)
Alblasserdam	388.500	5,62	150
Almelo	346.875	11,24	134
Beringen	166.500	11,24	65
Den Bosch	444.000	5,62	171
Deventer	83.250	11,24	33
Geel	194.250	11,24	75
Groningen	321.900	5,62	124
Hengelo	832.500	5,62	321
Kampen	255.300	11,24	99
Leeuwarden	277.500	11,24	107
Lommel	166.500	11,24	65
Meerhout	1.110.000	3,75	427
Meppel	377.400	11,24	146
Nijmegen	444.000	5,62	171
Roermond	199.800	11,24	77
Rotterdam (Pernis)	277.500	3,75	107
Venray-Wanssum	346.875	11,24	134

This is also computed for the AUTOFLEX OSCAR II scenarios, see Table 6-13.

Table 6-13: Power demand for the AUTOFLEX OSCAR II scenarios

Scenario	P_{Total} (kWh/year)	T_{ZES} (h/ZES)	N_{ZES} (ZES/year)
20 daily services with OSCAR II	810.300	5,62	312
10 daily services with OSCAR II	405.150	11,24	156
Five daily services with OSCAR II	202.575	11,24	78
Three daily services	121.545	11,24	47

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with OSCAR II			
One daily service with OSCAR II	28.470	10,00	11
Two weekly services with OSCAR II	8.112	20,00	4
One weekly service with OSCAR II	4.056	20,00	2

From an operational perspective, the fact that the SCH-1 enables battery-electric terminal equipment in areas where there is currently no zero-emission energy available to these is a major first step towards operational electrification of the inland waterways – especially in smaller and more impromptu terminals such as the Temporary Port Terminals (TPTs). This significantly extends the potential operational scope of the TPTs and may allow them to scale more effortlessly with an increase in throughput and/or demand for transport services. At the same time, the SCH-1 does not achieve full energy independence. Instead, it relies entirely on energy provision in charging hubs (SCH-2 and above) from upstream in the ecosystem. If those charging hubs face congestion or potential energy supply shortages (whether from their own energy infrastructure or from the grid), the SCH-1 operations will be immediately affected. Thus, while the SCH-1 may offer energy resilience in the form of ZES containers to circumvent local disturbances in the energy production or share of renewable energy in the grid, those same characteristics may also make the SCH-1 *less* resilient if careful coordination is not struck with more advanced SCH configurations and the AUTOFLEX transport system as a whole. Within the AUTOFLEX transport system, the SCH-1 runs an energy deficit and becomes an energy leech that requires the delivery of charged ZES containers and will return empty ones. However, this may prove a substantial asset and value proposition for TPT-related operations.

From a financial perspective, the SCH-1 exhibits extremely low CAPEX. Actually, it may be that the only investment is in mobile charging cables that can be connected to the ZES containers to allow terminal equipment and last mile vehicles to charge at the SCH-1 premises. Outside of this, there are no noteworthy CAPEX requirements. Investments may be more "operational" in nature, as the layout of the terminal may require slight replanning to allow for areas with ZES containers, but even this seems a rather trivial investment. On the other hand, the SCH-1 offers various financial benefits stemming from the ability to participate in green logistics with minimal investment and potential revenue for reselling ZES energy to last mile vehicles. Nevertheless, the SCH-1 cannot capture value directly from renewable energy generation or larger energy trading, which are opportunities that more advanced SCH constellations may be able to.

In sum, the SCH-1's main bottleneck is the consequent battery logistics coordination that are required to keep the SCH-1 feasible. This required forecasting how many "full" and "empty" ZES containers are in circulation (including when and where), how the SCH-1 energy needs can be accomplished through freight-based vessel delivery schedules and how many "spare" ZES containers the SCH-1 location would need to avoid "blackout". This is intimately dependent on the throughput of the site and the overall centrality of the site within the larger AUTOFLEX transport system [84].

6.4.3. LEVEL 2 – THE CHARGING-ENABLED SCH

From a technical perspective, the Stow&Charge Hub - Level 2 (SCH-2) is the first configuration in which the terminal functions not only as a transshipment point for mobile energy units

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(i.e. ZES containers) but also recharges and redistributes these units into the AUTOFLEX transport system. Thus, the SCH-2 directly contributes to ensuring that the AUTOFLEX transport system has sufficient energy in circulation such that all (or almost all) of its related transport can be done in a green and sustainable manner.

Thus, in addition to the SCH-1 architecture, the SCH-2 architecture also includes:

a) One or more dedicated charging stations (if charging stations for ZES containers, terminal equipment and last mile vehicles are separated).
b) Electrical upgrades such as the necessary transformer capacity/-ies, cabling (either underground or along the periphery) and grid protection systems (switches etc.) such that higher charging loads can be supplied and guaranteed.

However, the SCH-2 does not generate its own renewable energy (i.e. there are no PV panels, nor wind turbines or similar). This means that all energy used for charging either ZES packs or vehicles at the SCH-2 relies on electricity from the local grid – electricity that may not come from a renewable energy source. It also means that the SCH-2 remains exposed to potential fluctuations in electricity prices, and thus its "resilience" and "feasibility" become dependent on parameters that are not within the immediate control of the terminal.

In the SCH-2 configuration, the terminal is expected to deliver energy to both the ship and the truck transports. Thus, we define the following variables:

- Last mile trucking energy consumption: 1.5 kWh/km (blended rate based on Shoman et al. [89])
- Last mile trucking distance (average per TEU): 15 km
- Ship energy consumption: 5.200 kWh* (i.e. two ZES battery containers of 2.600 kWh each)

**This is a conservative assumption as the AUTOFLEX vessel can serve most routes with one ZES pack (see section 1.4.3).*

The ZES charging station can recharge two ZES battery containers in parallel in just 2.5 hours. Given that each ZES battery container contains 2.600 kWh, this implies that the ZES charging station can deliver 5.200 kWh per 2.5 hours. If the ZES charging station was to be recharging continuously throughout the day, this would further imply 9.6 recharging cycles per day. This means that the ZES charging station, theoretically, can deliver 49.920 kWh/day or 18.220.900 kWh/year (i.e. 18,22 GWh/year). Mathematically, we can express this in the following way:

$$P_{Charging\ Station} = 9{,}6 * 365 * (2 * 2600) = 18.220.800\ kwh/year$$

From an energy surplus perspective, i.e. noting that the SCH-2 must provide recharged ZES containers back into the ecosystem to balance the *energy deficits* created at SCH-0 and SCH-1 sites, this means that most SCH-2 would, theoretically, be well adapted to become an energy-supply hub with a single charging station. Furthermore, the capacity-utilisation metric "how much of the ZES charging station capacity is consumed by the terminal itself (including ship-related, terminal-related and truck-related energy needs)?" can be computed. We will call this the charging station utilization rate.

$$U_{charging\ station} = \frac{P_{terminal} + P_{ship} + P_{truck}}{P_{charging\ station}}$$

If $U_{charging\ station} > 1$, then the terminal is an energy surplus node. Oppositely, if $U_{charging\ station} < 1$, then the terminal is an energy deficit node.

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Do note that for SCH-0 and SCH-1, the terminal is not deemed responsible for providing the inland ship with energy (hence P_{ship} has been set to 0). However, for SCH-2 and above, P_{ship} will be included and set to 5200 kwh per 24 TEU (i.e. two fully recharged ZES containers per one voyage with 24 TEU; the max capacity of the ship).

Another important parameter to determine apart from whether a terminal is in energy surplus or deficit with one ZES charging station is the follow-up question: "how much surplus or deficit?". This will be called the power balance and will be determined as the number of ZES containers that the surplus or deficit would cover.

$$ZES_{balance} = \frac{P_{charging\ station} - (P_{terminal} + P_{ship} + P_{truck})}{2600}$$

Consequently, based on the $P_{charging\ station}$, $U_{charging\ station}$ and $ZES_{balance}$ variables, the following breakdown of the terminal energy independence can be determined, see Table 6-14.

Table 6-14: Energy balance per terminal category

Name	P_{total} (GWh/year)	$U_{charging\ station}$	$ZES_{balance}$
XXL terminal	121,895	6,69	-39.875
XL terminal	48,758	2,68	-11.745
L terminal	30,474	1,67	-4.713
M terminal	12,190	0,67	+2.320
S terminal	4,876	0,27	+5.133
XS terminal	2,424	0,13	+6.076
XXS terminal	1,212	0,07	+6.543

As can be seen from Table 6-14, only M-terminals and smaller exhibit an energy surplus when the ship energy requirements are factored into the equation. However, with two charging stations, the L terminal configuration becomes an energy surplus node, and with three charging stations, the XL terminal configuration becomes an energy surplus node. Only the XXL terminal appears to be an unrealistic case in this regard, as it requires seven charging stations before becoming an energy surplus node, indicating that SCHs are not necessarily well suited for terminals with large cargo volume throughputs. When comparing this finding against the 17 validation terminals (see Table 6-15 below), we see that 5 of 17 terminals would be an energy surplus hub with a single ZES charging station, if the ZES containers were used as energy for ships, terminal equipment and last mile vehicles all together.

Table 6-15: Energy balance validation terminals

Location	P_{total} (GWh/year)	$U_{charging\ station}$	$ZES_{balance}$
Alblasserdam	20,478	1,12	-868
Almelo	18,284	1,00	-24
Beringen	8,777	4,82	+3.632
Den Bosch	23,404	1,28	-1.994
Deventer	4,388	0,24	+5.320
Geel	10,239	0,56	+3.070
Groningen	16,968	0,93	+482
Hengelo	43,883	2,41	-9.870
Kampen	13,457	0,74	+1.832
Leeuwarden	14,627	0,80	+1.382
Lommel	8,777	0,48	+3.632
Meerhout	58,510	3,21	-15.496

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Meppel	19,893	1,09	-643
Nijmegen	23,404	1,28	-1.994
Roermond	10,532	0,58	+2.957
Rotterdam (Pernis)	14,628	0,80	+1.382
Venray-Wanssum	18,284	1,00	-24

The 17 real-world validation terminals offer a glimpse into how the unified AUTOFLEX energy ecosystem could function. Some terminals are running a ZES container surplus while others are running a ZES container deficit. In its depicted state, the overall ecosystem runs a deficit of -7.224 ZES containers per year on the $ZES_{balance}$. However, if adding two more charging station, the $ZES_{balance}$ becomes +6.792. This allows the entire ecosystem not to recharge ZES containers at full rate, but to tailor the recharging rate such that the $ZES_{balance}$ reaches 0 in practice. This is done by e.g. adding an additional charging station at sites like Meehour or Hengelo, two terminals with large deficits, or identifying strategic locations within the network where additional charging stations would reach the most number of terminals in the shortest distance/time.

For the AUTOFLEX OSCAR II scenarios, see Table 6-16, one will find that scenarios with multiple OSCAR II vessels per day will still be energetically in surplus with a charging station. This somewhat matches with the notion of the larger terminal from the terminal categories and doubles down on the notion that fully-fledged Stow&Charge Hub (SCH) energy provision "hearts" that pump energy out to the rest of the AUTOFLEX transport system should not necessarily be the terminals with the largest cargo throughput per year.

Table 6-16:AUTOFLEX OSCAR II scenario energy balance

Scenario	P_{total} (GWh/year)	$U_{charging\ station}$	$ZES_{balance}$
20 daily services with OSCAR II	42,712	2,34	-9.420
10 daily services with OSCAR II	21,356	1,17	-1.206
Five daily services with OSCAR II	10,678	0,59	+2.901
Three daily services with OSCAR II	6,407	0,35	+4.544
One daily service with OSCAR II	2,124	0,12	+6.191
Two weekly services with OSCAR II	0,605	0,03	+6.775
One weekly service with OSCAR II	0,303	0,02	+6.892

From an operational perspective, the SCH-2 upgrades the terminal from merely a passive battery-handling energy node to an active energy distribution node within the AUTOFLEX transport (and energy) ecosystem. The key operational benefits from this include extending the reach of the AUTOFLEX inland vessels in particular and inland vessels in general – a common conundrum for both electric truck and electric ship transports. Furthermore, the energy availability at the terminal becomes more stable – both for ships, terminal equipment and road vehicles. Thus, the hyper-attentive planning of SCH-1 where the availability of energy containers at sites becomes crucial such that operations does not stop is not as much

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of a problem for SCH-2 terminals. This stability and predictability directly influence operational performance and would be the aim for many inland terminals engaged in the greenification of transport chains.

However, the SCH-2 also entails a few operational challenges. For instance, because the terminal draws power from the grid, peak-power management becomes critical. Grid-connected port terminals have historically faced load-management challenges as they electrify cargo-handling equipment [90]. While this challenge is predominant in larger port terminals, it will also be a potential challenge worth noting for inland terminals in general. Also, as mentioned, potential outages in the grid, variations in the renewable energy sources within the overall energy balance of the grid and fluctuations in energy prices may directly affect operational feasibility or charging at the SCH-2 – a challenge which may be further complicated by the geographical location of the SCH-2 terminal.

From a financial perspective, the SCH-2 may not require significant CAPEX as this entirely depends on the potential business model deployed for the charging station. For instance, ZES repeatedly offers to rent space at terminals (potentially acquiring this space for free) and sell the energy provided by the ZES containers "as-a-service". That is, ZES (together with the large Dutch bank *ING*) deploys a *pay-per-use* financial model for the ZES battery containers. This means that ship operators do not purchase ZES containers; instead, they are charged a rental fee for the battery container itself and a variable fee based on the exact amount of energy consumed from the battery container (ZES compares this to a traditional home energy bill where homeowners pay a fixed charge for the grid connection to their house and a charge for the energy used within their house). However, this model only works if the ship operator does not run out of battery-enabled energy throughout their transport schedule – and would not have to wait exacerbated times for the battery containers to be available/recharged. If this is the case, the underlying value proposition of the service promise collapses. Said differently, the *pay-per-use, energy-as-a-service* model of ZES only works if the ship never experiences "energy scarcity" during operations.

To guarantee this, ZES must ensure that charging stations are strategically placed throughout the inland waterway network so that battery containers can be exchanged frequently, predictably and with minimal downtime. The ZES charging station thus becomes the principal enabling asset underpinning the entire pay-per-use model. Consequently, the charging station cannot (or should not) generate direct revenue on its own as it is indispensable for making the energy-as-a-service model commercially (and operationally) viable. From this, it follows logically that the deployment and financing of charging stations within the network is not an optional or external costs: they must be a necessary strategic expenditure for the AUTOFLEX energy providers themselves – in this case, ZES. This "infrastructural bootstrapping" dynamic is not unique to the ZES charging stations and battery containers: for instance, tech giants often spend extreme amounts of money in developing data centres that do not recover costs if treated as a standalone product, but enable subscription services (such as Office 365, Gmail, AWS etc.) which are highly profitable – yet they could not be so without the data centres.

Therefore, the SCH-2 configuration will not have to undergo significant CAPEX investments. It may be that no to minimal investment is needed for a charging station to be deployed and that the terminal in question would merely need to provide sufficient space and, potentially, high-voltage/-capacity grid connection (transformers, cables, switches etc.) for the charging station if this is not already included as part of the "infrastructural bootstrapping" setup. From an OPEX perspective, the SCH-2 terminal (or whomever may be responsible for providing the

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energy in the charging station, e.g. ZES) pays full market price for the electricity used to charge the battery containers. Energy prices in Europe are rather volatile: they fluctuate with significant amounts both geographically and temporally (depending on weather, demand shifts, the distribution of different energy sources and general market disruptions) with hourly volatility over 1000% (i.e. much more “dynamic” than the stock market). Consequently, SCH-2 terminals that rely on the European grid to deliver energy may become financially (and operationally) exposed to this volatility, which in turn may determine the (temporal) viability of using the SCH-2 terminal as a charging hub. Oppositely, if sufficient battery containers are available at the site, the SCH-2 terminal may engage in day-ahead or intraday energy markets in order to exploit lower price windows or avoid high midday energy prices. This makes the energy procurement strategy at the site a core business task to enhance the feasibility (that is, the margin and/or potential energy price offered to ship and truck operators and to the terminals own cargo handling equipment).

While SCH-2 terminals may potentially generate complementary revenues through selling charges battery units, this only works if a balance is struck with the given energy provider, e.g. ZES, with regards to the CAPEX investment of installing the charging station. For instance, hypothetically at least, if the SCH-2 terminal and energy provider share the CAPEX of deploying the charging station at the site in question (and its OPEX), they too could share the revenue generated from it. Thus, any SCH terminal configuration that involved a *charging station* should undertake a collaborative cost-benefit analysis with their energy provide to assess how to create win/win CAPEX, OPEX and revenue structures at the benefit for both partners. In addition, having a charging station and enabling the distribution of battery containers from an advantageous geographical location may make the SCH-2 terminal a strategically important node in the transport system’s energy ecosystem, which in turn may attract more vessel calls and logistics flows – calls that may be prompted both by logistics actors that require cargo distribution and by energy actors that require energy distribution. Thus, the erection of the charging station may indirectly offer more business to the terminal.

6.4.4. LEVEL 3 – PARTIALLY ENERGY-INDEPENDENT SCH

From a technical perspective, the Stow&Charge Hub - Level 3 (SCH-3) terminal directly builds on top of the SCH-2 by adding on-site photovoltaic (PV) energy generation to the terminal’s energy architecture. Therefore, in addition to the components already listed for SCH-1 and SCH-2, SCH-3 adds:

- PV installations. As carefully described earlier, PV installations come in different constellations and installations:
    - On the rooftops of existing warehouses, office buildings and other large roof surfaces on the terminal. This is the dominant and most feasible form of PV deployment in European logistics facilities and EU analyses confirm that rooftop PV solutions have the highest technical potential among non-ground-mounted systems.
    - Depending on spatial constraints, both/either directly on the ground in larger arrays or as raised canopies above the operational area (provided, as mentioned, that the installation would allow for reach stackers and cargo cranes (and other terminal equipment) to continue to operate without problems.
- Interfacing between the PV panel installation(s) and the charging station, including establishing the correct inverters, DC/AC conversion systems etc.

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- More advanced energy monitoring for tracking the generation of energy and the overall energy balance in the local terminal grid and for detecting and predicting potential outages, peaks or troughs.

The SCH-3 terminal does not include large-scale renewable energy production such as wind turbines, nor does it include any large-scale energy storage infrastructure in addition to the ZES battery containers. Consequently, particularly in the North/West part of Europe wherein the AUTOFLEX use cases are located, the SCH-3 terminal cannot be fully energy independent. While terminal in North/West Europe can offset a significant share of its annual electricity costs with on-site solar PV solutions, going completely energy-independent on PV exclusively, on a full year basis, is generally not realistic without massive roof/land area and very large (and expensive) energy storage solutions that provide the energy buffer for night, prolonged weather disturbances and deep winter sun deficits. Consequently, the SC3 cannot guarantee full energy independence and would rely, at least partly, on energy being delivered by the local energy grid.

If we assume that the use case area achieves around 1.000 kWh per kWp per year, that one m^2 of solar panel produces around 0.18 kWp (based on 200 Wp and SolarMathLab estimations), then we can deduce that in terms of PV energy, the SCH-3 can produce around 180 kwh per m^2 per year (for 200 Wp panels). Based on these estimates, we can calculate the numbers of the Table 6-17 below for each terminal constellation.

Table 6-17: Solar-based energy independence per terminal category

Name	Terminal Size (ha)	P_{total} (GWh/year)	PV area needed (ha)	% of site covered in PV
XXL terminal	15,0	121,90	67,72	451,5
XL terminal	7,0	48,76	27,09	387,0
L terminal	4,0	30,47	16,93	423,3
M terminal	3,0	12,19	6,77	225,7
S terminal	1,5	4,88	2,71	180,6
XS terminal	1,0	2,42	1,24	123,6
XXS terminal	0,5	1,21	0,62	123,6

As can easily be observed from Table X above, then it is unrealistic to make any SCH entirely energy independent on PV panels alone. For the largest terminal size, more that 4.5 times the terminal size must be covered in PV panels to ensure energy independence; an entirely unrealistic achievement. For the smallest terminals, the number is significantly smaller, but still much too large at 1.2 times the terminal size needed for sufficient PV coverage vis-à-vis energy independence. However, the PV panels are not without their value. For instance, for every 1 m^2 PV panel installed, the terminal would be able to generate energy for an additional 0.77 TEU in throughput. On the other hand, for every additional 1 TEU, the SCH would need an additional 1.33 m^2 of PV panels installed. While this is a rough estimate for the purpose of this deliverable, it creates an actionable rule of thumb that SCH can use to see what energy requirements are placed upon the terminal in terms of PV energy generation from an increase in cargo throughput. This allows the terminal to stay somewhat agile towards increases in business.

From the 17 real-world validation terminals (see Table 6-18), we see that only one terminal – the Rotterdam (Pernis) terminal – would be able to go fully energy independent on PV panels if it was to utilize 95% of its terminal space. While this is theoretically possible, it is practically

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not. Consequently, the 17 real-world validation terminals confirm the hypothesis that the SCH-3 cannot obtain full energy independence on solar alone.

Table 6-18: Solar-based energy independence per validation terminal

Name	Terminal Size (ha)	P_{total} (GWh/year)	PV area needed (ha)	% of site covered in PV
Alblasserdam	4,8	20,478	11,38	237
Almelo	3,2	18,284	10,16	317
Beringen	3,0	8,777	4,88	163
Den Bosch	4,5	23,404	13,00	289
Deventer	1,5	4,388	2,44	163
Geel	3,4	10,239	5,69	167
Groningen	2,9	16,968	9,43	325
Hengelo	12,5	43,883	24,38	195
Kampen	2,3	13,457	7,48	326
Leeuwarden	2,5	14,627	8,13	325
Lommel	2,0	8,777	4,88	244
Meerhout	13,0	58,510	32,51	250
Meppel	3,4	19,893	11,05	325
Nijmegen	4,0	23,404	13,00	325
Roermond	1,8	10,532	5,85	325
Rotterdam (Pernis)	8,5	14,628	8,13	95
Venray-Wanssum	5,6	18,284	10,16	181

The AUTOFLEX OSCAR II scenarios tell a somewhat different story, see Table 6-19. While scenarios with daily OSCAR II services are not able to maintain energy independence on solar alone as all sites would require more than 100% of the surface area to be covered in PV panels. However, an interesting observation can be made on the weekly service scenarios. With two weekly services, “only” 67% of the terminal size, namely 0.34 ha (i.e. 3.400 m^2) would need to be covered by PV panels. While this is still in the higher end as most of the terminal area would ideally be used for cargo-related operations, it does provide valuable insights into how smaller terminals with less throughputs will find it easier to pursue energy independence. Further validating this notion, the scenario with one weekly OSCAR II service would need just 34% of the terminal (which is still quite high considering the focus on cargo-related operations), i.e. 1.700 m^2 of space. However, should the available terminal size be a little larger that the one stipulated here, the percentage of PV panels to overall terminal size would further decrease. Thus, energy independence may realistically be achieved in micro SCH terminals.

Table 6-19: Solar-based energy independence per AUTOFLEX OSCAR II scenario

Name	Terminal Size (ha)	P_{total} (GWh/year)	PV area needed (ha)	% of site covered in PV
20 daily services with OSCAR II	4,0	42,712	23,73	593
10 daily services with OSCAR II	3,0	21,356	11,86	395
Five daily services with OSCAR II	3,0	10,678	5,93	198
Three daily services with OSCAR II	1,5	6,407	3,56	237
One daily service with OSCAR II	1,0	2,124	1,18	118
Two weekly services	0,5	0,605	0,34	67

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with OSCAR II				
One weekly service with OSCAR II	0,5	0,303	0,17	34

From an operational perspective, the SCH-3 terminal is still exposed to grid-based volatilities in the price and availability of (renewable) energy, as mentioned. Notwithstanding, the terminal is replacing parts of its electricity consumption with self-generated solar energy and could, potentially, create additional revenue streams where renewable energy is sold back into the grid. This is particularly relevant if ZES battery containers can be used locally on the terminal as an energy buffer for the terminal's own equipment and could potentially be a way of lowering the price of the battery container consumption and/or the transshipment costs, if transshipment activities could be aligned outside midday peak prices. Thus, the SCH-3 terminals generally offer lower operational risks, as the terminal can still charge its equipment and container batteries (at least partially) using its own PV solutions, and higher AUTOFLEX transport network integration, as the site can be used as a semi-independent energy hub that can provide battery containers to the AUTOFLEX transport system with the certainty that at least some of the energy within these battery containers stem from a truly renewable energy source. Oppositely, however, the PV solutions may themselves be subject to fluctuations in energy output, especially on cloudy days and during winter months, and cannot support overnight charging/consumption unless "stationary" battery containers can be used as the necessary balance to the terminal (however, this probably would require an alternative payment structure not based on a *pay-per-use* model as asset utilization would not be optimized for *energy consumption* but for *energy buffering*). Furthermore, most inland terminals may have limited roof or ground space to meaningfully scale PV installations – an issue that is well documented across PV adoption studies in the EU due to, amongst other things, fierce competition for land and infrastructure load limits.

From a financial perspective, the SCH-3 terminal is the first configuration that require a certain amount of CAPEX – primarily due to the costs associated with the installation and integration of PV panels and the necessary grid-integration upgrades (inverters, converters, switches, cables etc.). The exact costs vary depending on the scale of the installation(s) and the available space allocated for the purpose (e.g. rooftops). There may also be light increase in OPEX to maintain the energy-production-system operational continuously. On the other hand, as mentioned, PV panels provide (near) zero-cost energy during daylight hours, which may be a significant cost saving for the terminal itself, and lower the exposure of the terminal to volatile electricity prices. Thus, the increased CAPEX may be relatively quickly amortized by the decrease in energy-related OPEX (although the payback period may vary across seasons and regions). Furthermore, if the energy-production of the SCH-3 terminal is carefully aligned with energy supply-and-demand, the SCH-3 terminal may be able to add additional revenue streams through the selling of renewable energy (either to the grid or to the charging station, if the terminal itself is not involved in the business of the charging station – see previous discussion on the *pay-per-use* model in the SCH-2 section. Furthermore, being able to deliver renewable energy is battery containers may attract additional throughput of both battery and cargo containers – akin to the arguments made for SCH-2, but arguably even more so.

6.4.5. LEVEL 4 – FULLY ENERGY INDEPENDENT SCH

From a technical perspective, the Stow&Charge Hub – Level 4 (SCH-4) incorporates all the previous configurations, i.e. battery containers, charging stations and renewable energy

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generation (likely through PV panels), but expands this latter component such that the terminal becomes a fully energy-independent microgrid based on renewable energy. While this could hypothetically be accomplished by PV panels alone, this is practically and realistically unlikely. Thus, for the purposes of this deliverable, the SCH-4 adds a further renewable energy source: wind turbines. While the energy output of wind turbines is highly sensitive to average wind speeds, it is likely necessary that the SCH-4 must supplement and accompany this wind turbine with the PV panels and additional battery storage capacity (e.g. via battery containers or fixed battery installations) to ensure that the terminal remains energy independent throughout fluctuations in its energy production. Thus, while the SCH-4 adds a new component in the capability to harvest renewable energy from winds, wind turbines are not the defining characteristics per se: full annual energy balance is. However, wind-derived energy often provides the necessary capacity because port-related analyses consistently show that wind-derived energy provides much more stable and higher energy production that is better suited for larger industrial loads. For example, wind turbines are often argued to be the better option for hydrogen production in ports for this precise reason. Consequently, the SCH-4 can be seen as the most advanced energy hub within the AUTOFLEX system[3].

Table 6-20: Wind-based energy independence per terminal category

Name	Energy needs (GWh/year)	Wind turbines	Energy surplus (GWh/year)
XXL terminal	121,90	8 * 6 MW	+6,10
XL terminal	48,76	4 * 6 MW	+15.24
L terminal	30,47	2 * 6 MW	+1.53
M terminal	12,19	1 * 5 MW	+1.31
S terminal	4,88	1 * 4 MW	+6,62
XS terminal	2,42	1 * 4 MW	+9,08
XXS terminal	1,21	1 * 4 MW	+10,29

For the 17 real-world validation cases, we see a similar pattern, see Table 6-21. Many terminals become energy independent with just a single windmill, while the far majority become fully energy independent, occasionally with a substantial energy surplus that could be traded off, with two windmills.

Table 6-21: Wind-based energy independence per validation terminal

Name	Energy needs (GWh/year)	Wind turbines	Energy surplus
Alblasserdam	20,478	2 * 4 MW	+2,52
Almelo	18,284	2 * 4 MW	+4,72
Beringen	8,777	1 * 4 MW	+2,92
Den Bosch	23,404	2 * 5 MW	+3,60
Deventer	4,388	1 * 4 MW	+7,11
Geel	10,239	1 * 4 MW	+1,26
Groningen	16,968	2 * 4 MW	+6,03
Hengelo	43,883	4 * 5 MW	+10,11
Kampen	13,457	1 * 5 MW	+0,043
Leeuwarden	14,627	1 * 6 MW	+1,372

[3] Hydrogen-based energy for the port logistics of the future
Europe to get 1st climate-neutral container terminal based on hydrogen tech | World Ports Organization

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Lommel	8,777	1 * 4 MW	+2,723
Meerhout	58,510	4 * 6 MW	+5,490
Meppel	19,893	2 * 4 MW	+3,107
Nijmegen	23,404	2 * 5 MW	+3,596
Roermond	10,532	1 * 4 MW	+0,968
Rotterdam (Pernis)	14,628	1 * 6 MW	+1,372
Venray-Wanssum	18,284	2 * 6 MW	+13,716

It is important to reiterate that the SCH-4 is defined by its energy autonomy, not its wind turbine ownership. Said differently, it is because a terminal is fully energy independent and operates under its own microgrid that it is a SCH-4 – not because it has erected one or more wind turbines. However, inland terminals (and terminals in general), would probably not be able to achieve full energy independence on PV panels alone. Therefore, the erection and ownership of wind turbines is intimately tied to the SCH-4 constellation – at least in the context of the AUTOFLEX transport system. Do, however, note that the maximum annual throughput capacity is not necessarily the same as the actual annual throughput – nor will the entirety of the throughput necessarily be suitable to the AUTOFLEX system. Consequently, the total energy consumption needs (GWh/year) in the above table are on the (extremely) high end of the scale of the SCH-4 energy needs for the SCH-4 to become fully energy independent. For a more realistic throughput estimation, we can calculate annual throughputs based on OSCAR II service frequency (see Table 6-22 below).

Table 6-22: Wind-based energy independence per AUTOFLEX OSCAR II scenario

Name	Energy needs (GWh/year)	Wind turbines	Energy surplus
20 daily services with OSCAR II	42,712	3 * 6 MW	+5,29
10 daily services with OSCAR II	21,356	2 * 4 MW	+1,64
Five daily services with OSCAR II	10,678	1 * 4 MW	+0,82
Three daily services with OSCAR II	6,407	1 * 4 MW	+5,09
One daily service with OSCAR II	2,124	1 * 4 MW	+9,38
Two weekly services with OSCAR II	0,605	1 * 4 MW	+10,90
One weekly service with OSCAR II	0,303	1 * 4 MW	+11,20

If we again consider the 17 real-world cases as a common ecosystem where some SCHs are in surplus and some in deficits, while trying to minimize the amount of wind turbines to ensure lowest possible CAPEX for the ecosystem at a whole, but also ensuring that the ecosystem as a whole is at an energy surplus, we get another piece of insight into the working of the AUTOFLEX Stow&Charge hierarchy and balance. Where relevant, terminals have been supplemented with PV panels to make sure that the overall energy balance of the ecosystem remain exactly 0 – that is, there is no surplus nor a deficit. The ecosystem produces and consumes its own renewable energy.

From an operational perspective, the SCH-4 is the first constellation that guarantees renewable ZES charging year-round, independent of grid conditions, market pricing and external charging hubs. Consequently, the SCH-4 is a primary energy supply node in the

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AUTOFLEX ecosystem. The hub allows for the continuous charging of ZES containers using renewable energy regardless of external supply constraints and fluctuations in the energy grid, allowing for the redistribution of surplus renewable energy (via ZES) to less advanced SCH constellations (SCH-0, SCH-1, SCH-2 & SCH-3). Arguably, the SCH-4 would be able to offer highly stable energy availability for electrified terminal equipment too.

Wind plays a key operational role in the SCH-4, and with its somewhat predictable and often night-time and winter-peak output patterns, it is an opportune solution for terminals that want to achieve not just energy independence, but energy surplus. However, as mentioned, the wind would most likely work in tandem with PV panels, which often produce energy in less predictable, daytime and solar-peak outputs – more or less the polar opposite of wind-based energy production. Consequently, using the two in tandem can ensure that renewable energy is continuously produced regardless of the prevailing season, weather and temperature. However, the SCH-4 also face some operational challenges. For instance, the placement of the wind turbine must be such that turbulence, noise and general environmental impacts to wildlife etc. are considered with utmost care. Furthermore, given the high energy output of wind turbines, high-voltage protection schemes must be in place to manage faults and backfeed etc. Also, as was recently experienced in the blackout of the Iberian Peninsula, overproduction of renewable energy – energy sources that are often binary in their production output (i.e. they are on or off, not 50% on, as an example) – may risk overproduction of energy with an increase in energy frequency in the microgrid and the automatic deactivation of energy production.

From a financial perspective, the SCH-4 requires the highest capital investment of the SCH hierarchy, with major cost components including wind turbine procurement, including constructing the wind turbine foundation and integrating into the existing electrical grid (which is often the most expensive cost item) and reinforced electrical infrastructure locally, including microgrid controllers and switchgear for energy import/export. Oppositely, the financial benefits of the SCH-4 include full insulation from electricity price volatility in the grid, which enables more predictable OPEX, and a guaranteed green environmental footprint, which is a strong competitive advantage. Furthermore, the SCH-4 may be able to create additional revenue streams from selling surplus energy to the grid and/or distributing charged ZES units into the wider AUTOFLEX transport and energy network.

6.4.6. THE STOW&CHARGE HUB HIERACHICAL STRUCTURE

To support the systematic electrification of inland waterway transport within the AUTOFLEX network, terminals must be assessed and categorised according to their technological readiness and energy-handling capabilities. For this purpose, the Stow&Charge Hub Levels Matrix was established as a tailorized classification method. It allows an evaluation of terminals across different operational routes in terms of their feasibility and structure as possible SCHs.

The SCH matrix defines five levels of terminal development, ranging from conventional cargo terminals (Level 0) to fully integrated energy hubs (Level 4). These levels are distinguished by the presence or absence of five key capabilities:

- WEP – On-site or adjacent Wind Energy Production
- SEP – Solar Energy Production, either roof-mounted or in surrounding open fields
- CSs – Charging Stations for ZESpacks or equivalent battery containers

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- BCs – Ability to handle and store Battery Containers (ZESpacks)
- CHE – Availability of Container Handling Equipment such as reach stackers or gantry cranes

This classification enables terminals to be identified with a certain technological readiness level. Those at lower levels can be targeted for gradual upgrades, while those at higher levels can serve as primary nodes in the network of SCHs.

Table 6-23: SCH matrix for the evaluation of potential locations

Level	WEP	SEP	CSs	BCs	CHE	Description
0	✕	✕	✕	✕	✓	Conventional inland terminal with no energy-related functionality
1	✕	✕	✕	✓	✓	Terminal can handle battery containers but cannot charge them
2	✕	✕	✓	✓	✓	Terminal supports charging operations but lacks renewable integration
3	✕	✓	✓	✓	✓	Terminal is partially energy-autonomous through solar production
4	✓	✓	✓	✓	✓	Fully integrated cargo & energy terminal with wind and solar generation

Based on this matrix several possible locations along the elaborated AUTOFLEX WACs were evaluated in terms of their feasibility as a SCH.

6.5 POTENTIAL STOW&CHARGE LOCATIONS

Having defined the hierarchical Stow&Charge Hub (SCH) configurations, a natural next step is to inspect the clusters of renewable energy sources (see section 4.6 (F) Renewable Energy Sources (RES)) to identify potential locations for SCHs and their configurations. However, do note that this require a deeper understanding of energy needs of the AUTOFLEX transport ecosystem, which is partly based on identifying precise transport demands that must be serviced. This is beyond this deliverable and will be dealt with in later tasks of the AUTOFLEX project.

Together, the five official AUTOFLEX WACs provide a complete representation of the vessel's intended operational profile with each corridor and route reflecting unique combinations of sailing distance, terminal capability, renewable energy availability and logistical relevance. These characteristics form the basis for subsequent analyses of Stow&Charge hub placement, required grid capacity, ZESpack-buffer sizing, and corridor specific operational strategies.

At a cruising speed of 7 km/h, every corridor can be completed comfortably on a single ZESpack with considerable reserve margin. This enables simple and predictable energy logistics, as terminals need only ensure the availability of at least one fully charged ZESpack for every arriving vessel. However, as operating speed increases to 10 km/h or 12 km/h, energy demand rises dramatically and the percentage of ZESpack capacity consumed on long routes approaches critical thresholds. Under such conditions, the reliability of SCH operations depends increasingly on the terminal's ability to deliver rapid charging cycles, maintain sufficient buffer stocks, and ensure adequate grid capacity.

Environmental-sensitive effects further increase the importance of properly dimensioned infrastructure. Winter operation, river currents and wind loads can reduce energy margins

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by an additional 10–40%, particularly on long routes such as the routes on WAC2 and WAC5. To maintain year-round operational reliability, terminals must therefore be equipped to compensate for these variations through larger buffer capacity, improved charging throughput or the integration of renewable-energy systems that reduce dependence on external grid fluctuations.

In combination, the energy-demand results confirm that SCHs must be designed not only around nominal operating conditions but also with enough redundancy to absorb real-world variations in vessel performance and environmental conditions. The following sections build on these insights to identify suitable terminal locations, define the technical requirements for charger installation, assess spatial constraints, and evaluate opportunities for integrating local renewable-energy production without interfering with cargo operations.

Selecting appropriate terminals for SCH infrastructure requires a structured assessment approach that combines spatial, technical, operational, and energy-system criteria. The suitability of a terminal as a SCH is determined not only by its physical characteristics, such as available space or quay infrastructure, but also by its integration into the broader logistics network and its ability to support high-power charging and ZESpack handling without disrupting existing cargo operations. To evaluate terminals feasibility as SCHs across all AUTOFLEX WACs and routes, certain key criteria/ requirements have been identified.

A fundamental requirement for SCH locations is the availability of sufficient area to install both the ZESpack charging zone and buffer storage. Based on equipment and safety clearances, the minimum recommended footprint for a charging unit is approximately 15 × 25 metres, which must be placed in a location that ensures unobstructed access for reach stackers or cranes. This area must be complemented by additional buffer space for storing charged and discharged ZESpacks, ideally within close proximity to minimise internal transport distances.

A second and decisive parameter for SCH locations is the proximity of existing renewable energy sources, such as those identified in section 4.6 above. Terminals located near large roof-mounted solar arrays, adjacent solar fields or operational wind turbines offer clear advantages as they may be able to exhibit more advanced SCH configurations with minimal CAPEX requirements. These energy sources can directly support local charging operations, reduce demand on the public grid and contribute to system-level emission reductions.

A third essential parameter for SCH locations is the availability of cargo-handling systems, particularly reach stackers, mobile harbour cranes, or gantry cranes capable of lifting and moving 20-ft ZESpacks. Since the battery modules are containerised, their handling integrates naturally into standard terminal workflows. Terminals lacking such equipment would require additional investment or significant changes to become suitable candidates.

A fourth and equally important parameter for SCH locations is the quality of grid connection. High-power charging requires access to medium- or high-voltage infrastructure capable of supporting at least one 1 MW MCS charging point, often with redundancy for reliability. Terminals located near industrial substations or energy-intensive clusters (such as Moerdijk or Antwerpen) typically offer better grid capacities than smaller, rural terminals.

Alongside these energy-technical aspects, intermodal connectivity plays a central role. Terminals with established road and, where available, rail links support multimodal logistics and increase the utilisation of SCH infrastructure. This criterion aligns with the project objective of enabling seamless integration between electric inland shipping and battery-electric truck last mile transportation.

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Finally, operational feasibility needs to be assessed. Suitable terminals require appropriate water depth, quay length and berthing conditions to accommodate the developed CEMT II AUTOFLEX vessel safely. They should also allow smooth approach and manoeuvring paths to avoid excessive thruster use or energy consumption during docking.

Beyond these infrastructural considerations, the terminal screening must incorporate insights from the vessel's energy-demand profile. Terminals located on longer or more energy-intensive corridors, particularly those on the routes of WAC2 and WAC5, must be able to support higher ZESpack throughput and larger buffer capacity. Similarly, terminals exposed to environmental sensitivities (such as river currents on the WAC3 routes) must provide sufficient operational reserves.

Together, these criteria create a holistic evaluation framework that can be applied consistently across all AUTOFLEX terminals. The following will assess the most interesting locations along the WAC1-5 corridors to identify where and how SCH configurations could be deployed. Given that some of the locations intersect multiple WACs, the following analysis will go through these locations alphabetically.

6.5.1. ALKMAAR

Location: Alkmaar	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✗
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-1: Analysis for a potential Stow&Charge hub in Alkmaar
Maps data: © 2021 Google

The potential terminal at Alkmaar corresponds to a typical Level 0 location, providing no container-handling capabilities without any on-site charging infrastructure or renewable-energy systems. Also, the terminal is not immediately next to the waterways and it appears to be a gas or liquid processing plant, which questions whether it is even capable of handling battery containers (BCs), nor is it certain that there will be demand for electric last mile transports (primarily due to the lack of existing container transport to the site). This limits its role within the Stow&Charge network to purely operational container movements, perhaps to a SCH Level 1 if the argument for utilising ZES battery containers on the terminal can be found.

Strengths:

- Good accessibility and functional quay layout.

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Limitations:

- No handling capacity for container or ZESpack movement.
- No existing charging infrastructure.
- No observable solar or wind energy production in the vicinity.
- Limited potential for local energy autonomy or expansion.

Role in the AUTOFLEX network: A terminal at Alkmaar could function mainly as a supporting terminal on the WAC2, suitable for logistical handling but not for energy exchange. To progress toward more advanced SCH Levels, the site needs to develop towards the utilisation of ZESpacks and the installation of a charging station and verification of grid connection capacity would be required. This would be at the cost of expanding the terminal into the surrounding green area.

6.5.2. AMSTERDAM – HOLLAND CARGO TERMINAL

Location: Amsterdam (Holland Cargo Terminal)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-2: Analysis for a potential Stow&Charge hub in Amsterdam Holland Cargo Terminal
Maps data: © 2025 Google | © 2025 Airbus

Amsterdam is home to several terminals. One of the dominant ones is the Holland Cargo Terminal, which qualifies as a Level 4 facility. This places it amongst the most advanced Stow&Charge-capable terminals in the AUTOFLEX network. With full renewable-energy integration (solar and wind), established charging infrastructure (albeit not ZES charging stations), battery-container logistics feasibility and comprehensive handling equipment, the terminal possesses the complete capability set defined in the matrix. While the windmills are not visible in Figure 6-2, some of them can be seen here.

Strengths:

- Supports full ZESpack logistics including handling, charging and storage.
- Solar and wind energy integration enables high energy-autonomy potential.
- Strong positioning within Amsterdam's multimodal logistics cluster.

Limitations:

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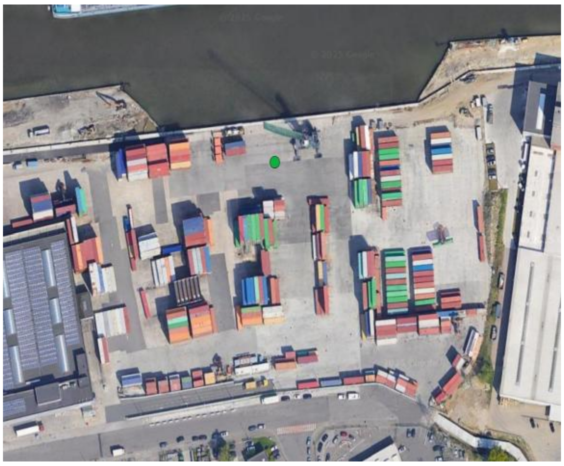
- Spatial constraints typical for dense metropolitan terminals may restrict expansion.
- High operational density may require dedicated zoning for safe and efficient SCH operations.
- ZES charging stations need to be installed

Role in the AUTOFLEX network: This terminal serves as a high-capacity Stow&Charge node at the northern end of the network. Given its full Level-4 feature set, it is well suited to handle frequent ZESpack exchanges and support future autonomous-vessel deployment.

6.5.3. ANTWERP – ALBERTKANAAL



Location: Antwerp (Albertkanaal)	
Container Handling Equipment (CHE)	✓
ZES Battery Containers (BCs) feasible	✓
ZES Charging Station (CS) feasible	✓
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 3	

Figure 6-3: Analysis for a potential Stow&Charge hub in Antwerp – Albertkanaal
Maps data: © 2022 Google

A potential terminal in Antwerp (on the Albertkanaal) qualifies as a Level 3 facility. With strong operational feasibility for ZESpack handling (BCs + CHE), established charging infrastructure (CSs – albeit not ZES charging station) and the presence of solar-energy production, the terminal is well-positioned to support regular Stow&Charge operations along the Belgian–Dutch corridor. Although wind-energy integration is absent, its solar-generation capacity provides partial renewable autonomy.

Strengths:

- Solar-energy installations support renewable-powered charging operations.
- Full operational capability: ZESpack handling, storage and charging is feasible.
- Strategically located on the Albertkanaal, enabling efficient links between Antwerp and both the Belgian and the Dutch inland waterway networks.
- Strong industrial grid access typical for the Antwerp logistics region.

Limitations:

- No wind-energy production limits diversification of renewable sources.
- Expansion potential may require reallocation of quay space due to high local utilisation.
- ZES charging stations need to be installed

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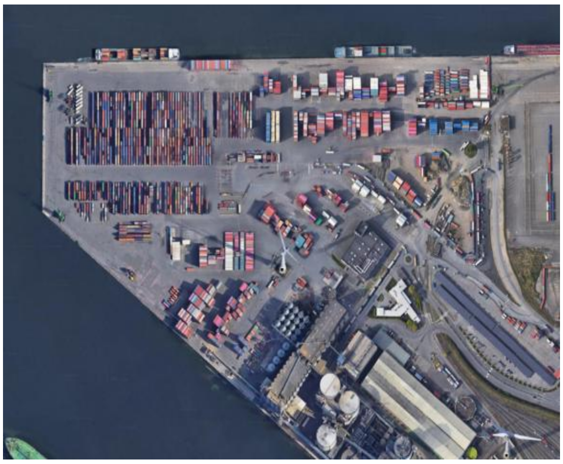
Role in the AUTOFLEX network: A terminal at Antwerp–Albertkanaal functions as a robust regional Stow&Charge hub, serving as a key link between Antwerp and inland Belgium. Its Level-3 capability set enables frequent battery-exchange operations, making it an important supportive node for long-distance electric navigation toward both Ghent and the Dutch routes.

6.5.4. ANTWERP – GRAANDOK



Location: Antwerp (Graandok)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-4: Analysis for a potential Stow&Charge hub in Antwerp – Graandok
Maps data: © 2022 Google

A potential terminal at Antwerp–Graandok qualifies as a Level 4 facility. With full ZESpack-handling capability (BCs + CHE) and established charging infrastructure (CSs – albeit not ZES charging stations), the terminal is operationally ready to support Stow&Charge activities. Solar- and wind-energy production at site and in the surrounding industrial area, provides a renewable-integration potential.

Strengths:

- Wind-energy integration provides renewable-based charging potential.
- Solar-energy available in the immediate vicinity (e.g. see Figure 6-4 to the right, just below the middle)
- Fully capable of handling battery containers (BCs) and performing all related logistics.
- Equipped with container-handling equipment suited for efficient vessel turnaround.
- Situated within Antwerp's central port system, ensuring excellent multimodal connectivity.

Limitations:

- High utilisation and dense port layout may constrain expansion of Stow&Charge operations.
- ZES charging stations need to be installed

Role in the AUTOFLEX network: A terminal at Antwerp – Graandok serves as a strong regional Stow&Charge node, complementing the Antwerp–Albertkanaal terminal. Its Level-4

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capability positions it well for handling medium- to high-frequency ZESpack operations and supporting energy-enabled cargo flows across the Antwerp port region.

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6.5.5. ARNHEM

Location: Arnhem	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✓
Stow&Charge Hub level (potential) = 0-4	

Figure 6-5: Analysis for a potential Stow&Charge hub in Arnhem
Maps data: © 2023 Google

A potential terminal at Arnhem is classified as a Level 0 facility. Although solar- and wind-energy production is present at or adjacent to the terminal (see Figure 6-5 and here), the terminal lacks all essential components required for Stow&Charge functionality. In particular, the absence of charging stations, battery-container handling capability and container-handling equipment prevents Arnhem from supporting battery-electric inland-shipping operations at present. Furthermore, space for container storage is limited. However, Arnhem may be able to transition to a Level 1 configuration with some ease if container handling equipment is invested in and the ZES battery containers can be integrated into the transhipment operations at the site. Further investments in charging stations and turning some of the brownfield areas into container storage, would enable a transition to Level 4. Currently, however, this is not the case and required investments appears to be significant.

Strengths:

- Solar- and wind-energy availability provides a foundation for future renewable integration.
- Strategic position on the eastern river corridor, offering potential long-term relevance.

Limitations:

- No charging infrastructure (CSs)
- No BC-handling capability and no CHE on-site, limiting logistical capacity.
- Limited space for container storage
- Significant investment needed to transition to level 4

Role in the AUTOFLEX network: A terminal at Arnhem currently functions as a non-operational Stow&Charge location, suitable only as a transit point for inland vessels. With substantial upgrades (including CHE investments, integrated use of BCs in terminal operations, expanding storage area, and a ZES charging station) the terminal could potentially evolve toward Level 4, although this would require considerable investment.

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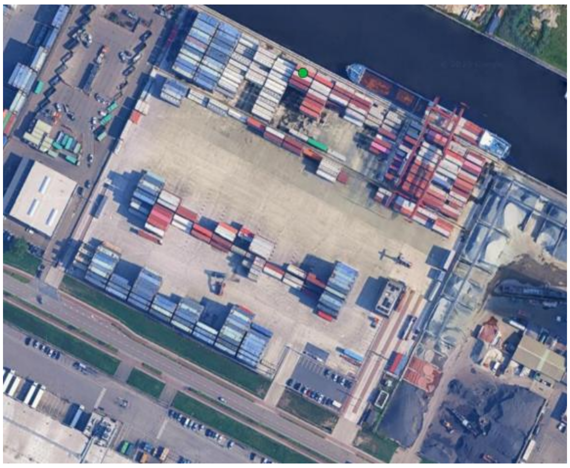
6.5.6. BERGEN OP ZOOM



Location: Bergen op Zoom	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✖
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-6: Analysis for a potential Stow&Charge hub in Bergen op Zoom
Maps data: © 2024 Google

A potential terminal at Bergen op Zoom qualifies as a Level 4 facility. Its combination of wind-energy availability from nearby windmill parks (to the west), full ZESpack handling capability and on-site charging infrastructure, positions it as a strong regional Stow&Charge terminal. Although the terminal lacks solar-energy integration at site, the presence of wind energy compensates for this and supports partial energy autonomy. It should be noted that relaying on the windmill park for zero-emission energy implies dependence on a third party.

Strengths:

- Access through grid to nearby wind-energy production, enabling renewable-powered charging.
- Full ZESpack logistics capability is feasible: CHE and BC handling in place, and charging systems can be installed.
- Well-positioned along inland corridors linking Rotterdam, Moerdijk and Belgian terminals.

Limitations:

- No solar installations at the terminal (there are some in the adjacent lots) reduce renewable-source diversity and limit resilience during low-wind periods.
- Dependence on third-party zero-emission energy supply (which is found close to the terminal)
- Expansion potential may depend on terminal zoning and available quay-side area.

Role in the AUTOFLEX network: A terminal at Bergen op Zoom functions as a robust mid-corridor Stow&Charge node, supporting energy provision for vessels operating between the Rotterdam–Moerdijk region and southern corridors. Even without solar integration, the terminal exhibits strong Level 4 potential. It should, however, be noted that the terminal is not energy independent as it depends on the third-party windmill park for zero-emission energy supply.

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6.5.7. BREDA

Location: Breda	
Container Handling Equipment (CHE)	✓
ZES Battery Containers (BCs) feasible	✓
ZES Charging Station (CS) feasible	✓
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 3	

Figure 6-7: Analysis for a potential Stow&Charge hub in Breda
Maps data: © 2024 Google

A potential terminal at Breda qualifies as a Level 3 facility. With solar-energy integration, full ZESpack-handling capability and operational charging infrastructure, the terminal demonstrates strong readiness for Stow&Charge operations. Although it lacks wind-energy integration, its combination of renewable solar production and complete handling capabilities make it a robust mid-corridor energy node.

Strengths:

- Solar-energy generation supports partial renewable self-sufficiency.
- Fully equipped for ZESpack handling, charging and storage.
- Well-positioned within the extended Moerdijk–Tilburg–Breda logistics axis.

Limitations:

- No wind-energy production limits renewable diversification.
- Terminal-area constraints may influence future expansion of energy infrastructure.

Role in the AUTOFLEX network: A terminal at Breda acts as a high-value secondary Stow&Charge hub, enabling reliable energy exchange along central Dutch corridors. With the addition of wind generation and energy independence, it has the potential to progress toward Level 4 in future development stages.

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6.5.8. DEN HAAG

Location: Den Haag	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✗
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-8: Analysis for a potential Stow&Charge hub in Den Haag
Maps data: © 2024 Google

A potential terminal at Den Haag classifies as Level 0, providing very limited capability for Stow&Charge integration. While the presence of solar-energy production slightly elevates its profile, the absence of charging stations and the inability to handle battery containers (BCs) prevents it from operating as an energy-enabled terminal. However, this is the same location as the TPT analysis in section 5.3.4.1 has identified as currently under redevelopment into a residential area. Consequently, it seems unlikely that the location will be used for larger energy-producing operations.

Strengths:

- Presence of solar-energy systems enables initial renewable-integration potential.
- Basic cargo-handling capability (CHE) could support limited container movements.
- Beneficial location within a dense metropolitan logistics corridor.

Limitations:

- No charging infrastructure for ZESpacks.
- Limited terminal footprint constrains the introduction of new energy systems.
- Redevelopment plans to turn the site into a residential area

Role in the AUTOFLEX network: A terminal at Den Haag functions primarily as a low-capacity, supporting terminal, unsuitable as a Stow&Charge node in its current state. Its solar-energy presence provides a starting point for incremental upgrades, but significant infrastructural improvements—particularly charging systems and BC-handling capability—would be necessary for it to reach SCH Level 2 or higher.

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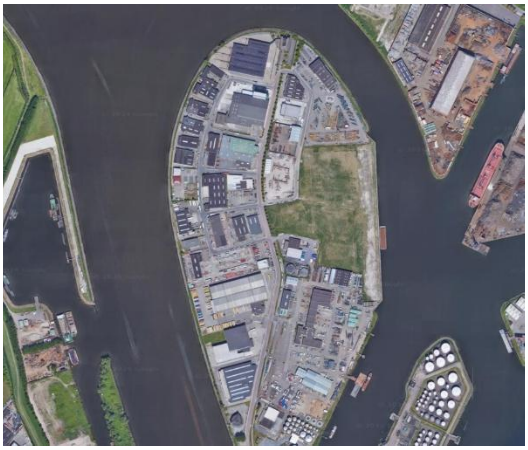
6.5.9. DORDRECHT



Location: Dordrecht	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✖
Wind-based Energy Production (WEP)	✖
Stow&Charge Hub level (potential) = 2	

Figure 6-9 Analysis for a potential Stow&Charge hub in Dordrecht
Maps data: © 2022 Google

A potential terminal at Dordrecht qualifies as a Level 2 facility, offering full operational capability for ZESpack handling and charging (CSs + BCs + CHE). Although the terminal lacks both wind- and solar-energy integration, its strong logistics base and established handling capacity allow it to function as a reliable operational Stow&Charge point.

Strengths:

- Can feasibly be equipped for complete ZESpack operations: charging, storage and handling.
- Beneficial location within the broader Rotterdam–Drechtsteden logistics corridor.
- Suitable quay infrastructure and intermodal links support high-throughput operations.

Limitations:

- Absence of renewable-energy production reduces on-site autonomy.
- Potential reliance on external grid capacity may limit expansion without reinforcement.

Role in the AUTOFLEX network: A terminal at Dordrecht serves as a key operational Stow&Charge terminal for central corridor routes. While it lacks renewable-energy systems for Level-3 classification, its robust handling and charging capability make it an essential intermediate logistics and energy node within the network.

Funded by the European Union

6.5.10. EINDHOVEN

Location: Eindhoven	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-10: Analysis for a potential Stow&Charge hub in Eindhoven
Maps data: © 2022 Google

A potential terminal at Eindhoven classifies as a Level 0 facility based on the provided capability profile. Although the presence of solar-energy production offers a minimal renewable baseline, the terminal lacks all essential operational components required for Stow&Charge functionality, including charging infrastructure, battery-container handling and container-handling equipment.

Strengths:

- Presence of solar-energy generation provides a limited foundation for future renewable-integration efforts.
- Strategic location within the Eindhoven industrial region and inland logistics corridor.

Limitations:

- No charging infrastructure (CSs), preventing ZESpack operation.
- No BC-handling capability or CHE, eliminating any logistical support for battery exchange.
- Operational capabilities remain extremely limited, restricting the terminal to basic mooring or low-intensity cargo activity.

Role in the AUTOFLEX network: A terminal at Eindhoven currently serves as a non-operational Stow&Charge location, functioning only as a potential future candidate for infrastructure development. To advance to Level 1 or 2, the terminal would require the installation of CHE, integrated use of BCs in the terminal operation (including the provision of a container crane or reach stacker that would be able to handle incoming ZES containers), and charging infrastructure.

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6.5.11. GHENT

Location: Ghent (DFDS)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-11: Analysis for a potential Stow&Charge hub in Ghent (DFDS-Terminal)
Maps data: © 2023 Google | © 2023 Airbus

The DFDS terminal in Ghent qualifies as a Level 4 facility, placing it among the most capable and strategically significant energy-enabled terminals within the AUTOFLEX network. The terminal combines full renewable-energy integration (wind and solar), charging infrastructure, battery-container handling capability and comprehensive container-handling systems, enabling seamless and high-frequency ZESpack exchange operations.

Strengths:

- Full renewable-energy portfolio with both solar and wind systems on-site.
- Complete capability for ZESpack handling, including charging, storage and transfer using modern CHE.
- Excellent multimodal connectivity through inland waterways, rail and road links.
- Large terminal footprint allows scalable integration of Stow&Charge operations.

Limitations:

- High operational intensity and vessel frequency may require zoning to avoid congestion.
- Energy-management optimisation may be needed to balance renewable production peaks with ZESpack charging loads.

Role in the AUTOFLEX network: The DFDS terminal in Ghent functions as a Tier-1 anchor hub for southern network operations. Due to its Level-4 capability set and its position at the interface between Dutch and Belgian cargo corridors, it is ideally suited for high-capacity battery-exchange operations; supplying ZESpacks to cross-border services; and supporting long-range electric navigation between Moerdijk, Antwerp and Ghent.

The terminal is one of the strongest candidates for integration into the Stow&Charge corridor system.

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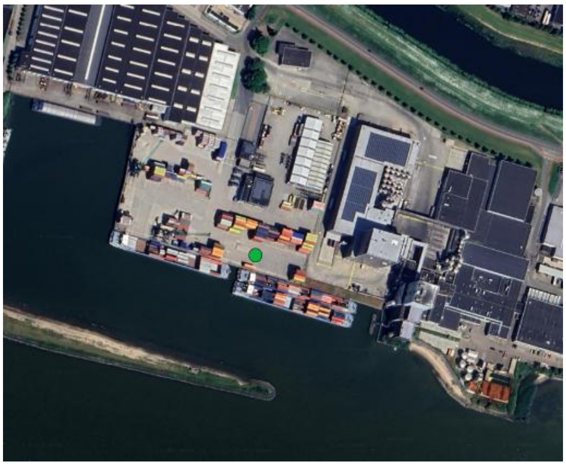
6.5.12. GORINCHEM



Location: Gorinchem	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 3	

Figure 6-12: Analysis for a potential Stow&Charge hub in Gorinchem
Maps data: © 2023 Google | © 2023 Airbus

A potential terminal at Gorinchem qualifies as a Level 3 facility. With solar-energy production, full ZESpack-handling capability and charging infrastructure, it is well positioned to support medium- to high-frequency Stow&Charge operations along central Dutch inland routes. Its strategic location near key waterways further enhances its relevance within the AUTOFLEX network.

Strengths:

- Solar-energy generation supports renewable-powered vessel charging.
- Fully equipped for ZESpack logistics: BC handling, CHE, and charging of ZES BCs being feasible.
- Inland location enables support for flows between Rotterdam, Waal, and Lek corridors.

Limitations:

- Absence of wind-energy production reduces renewable-energy diversity.
- Terminal expansion for high-capacity SCH operations may be constrained by spatial layout.

Role in the AUTOFLEX network: A terminal at Gorinchem functions as a mid-corridor Stow&Charge terminal, capable of supporting battery-electric operations across multiple inland routes. As a Level-3 location, it offers reliable energy support and can evolve further through integration of wind-energy systems.

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6.5.13. GOUDA

Location: Gouda	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-13: Analysis for a potential Stow&Charge hub in Gouda
Maps data: © 2024 Google

A potential terminal at Gouda is classified as a Level 1 terminal. Although it benefits from on-site solar-energy production, the absence of both container-handling equipment (CHE) and charging stations prevents the terminal from supporting battery-electric inland vessel operations. Operational capabilities are therefore restricted to minimal, low-complexity logistics activities.

Strengths:

- Presence of solar-energy capacity creates potential for future renewable integration.
- Strategically located along the routes of WAC2, offering geographic relevance.

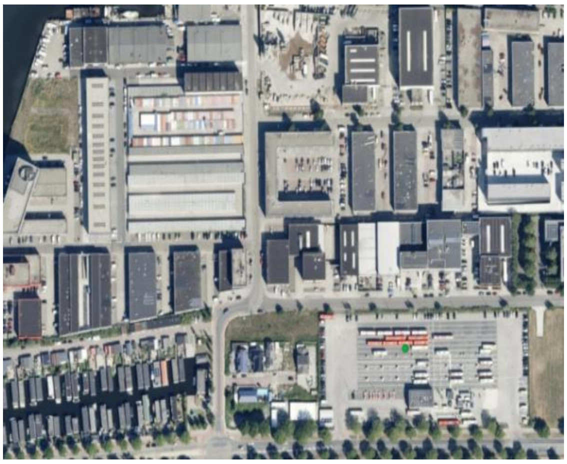
Limitations:

- No charging infrastructure for ZESpacks.
- No container- nor BC-handling equipment, limiting operational flexibility.
- Terminal layout appears constrained, leaving limited room for scaling energy infrastructure.

Role in the AUTOFLEX network: A terminal at Gouda currently functions as a low-capability support terminal rather than an operational Stow&Charge node. With targeted upgrades, such as for example acquiring more advanced CHE, installing a compact ZES charging station and expanding the solar-energy integration (potentially wind-energy too, if the financial assessment proves feasible), it could progress toward Level 2 or 3, or even 4. However, in its current form, it serves primarily as a transit or emergency-stop location.

Funded by the European Union

6.5.14. HAARLEM



Location: Haarlem	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✓
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✗
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-14: Analysis for a potential Stow&Charge hub in Amsterdam-Haarlem
Maps data: © 2022 Google | © 2022 Vexcel Imaging US, Inc.

Based on the provided capability profile, a potential cluster of terminals at Haarlem qualifies as a Level 0 site. While wind-energy production is available in the vicinity and the terminal can theoretically handle battery containers, the absence of solar power generation, charging stations and container-handling equipment (CHE) prevents the terminal from supporting any meaningful Stow&Charge operations.

Strengths:

- Nearby wind-energy facilities provide long-term potential for renewable integration.
- Functional quay structure suitable for basic vessel mooring.
- Brownfield provides space for container and BC storage, or charging equipment

Limitations:

- No available charging infrastructure for ZESpacks.
- No solar-energy installations detected on-site.
- Lack of container-handling equipment severely restricts BC movement and operational safety.

Role in the AUTOFLEX network: At its current capability level, Haarlem serves only as a basic transit or support location, not as an operational Stow&Charge node. Significant upgrades—particularly CHE acquisition, installation of CSs and integration of solar power—would be required for progression to higher levels.

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6.5.15. HELMOND

Location: Helmond	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 3	

Figure 6-15: Analysis for a potential Stow&Charge hub in Helmond
Maps data: © 2024 Google | ©2009 GeoBasis-DE/BKG

A potential terminal at Helmond qualifies as a Level 3 facility. With solar-energy production, full ZESpack logistics feasibility (BCs + CHE) and on-site charging infrastructure, the terminal is well positioned to act as a competent Stow&Charge node along the inland network. Although it does not integrate wind-energy production, its solar capacity and operational readiness provide substantial support for battery-electric inland vessels.

Strengths:

- Solar-energy generation enables partial renewable autonomy.
- Feasible with ZESpack handling and charging
- Equipped for container operations.
- Beneficial location within the Helmond/Eindhoven logistics area, supporting regional corridor flows.

Limitations:

- No wind-energy integration limits renewable diversification.
- Terminal expansion potential may be limited by local industrial zoning.

Role in the AUTOFLEX network: A terminal at Helmond serves as a strong mid-corridor Stow&Charge terminal, supporting vessels along the central Dutch routes. Its Level 3 capabilities make it well suited for regular ZESpack exchange and high-frequency charging operations.

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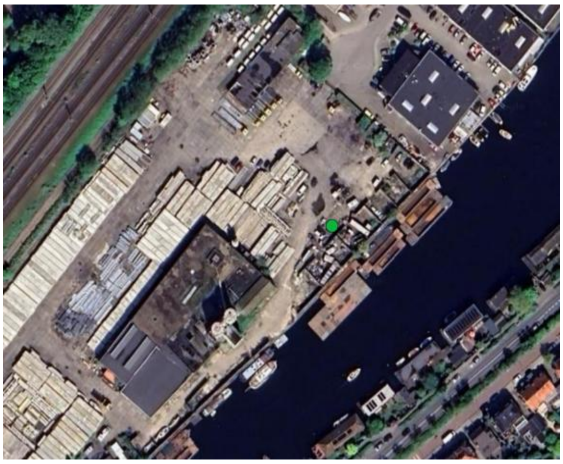
6.5.16. LEIDEN



Location: Leiden	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✗
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-16 Analysis for a potential Stow&Charge hub in Leiden
Maps data: © 2025 Google | © 2025 Airbus

A potential terminal at Leiden qualifies as Level 0, since none of the required Stow&Charge capabilities are present. The terminal does not exhibit any form of renewable-energy integration, charging infrastructure, battery-container capability or container-handling equipment. Its operational profile resembles that of a small or auxiliary quay without the technical provisions needed for energy-enabled logistics.

Strengths:

- Simple and accessible quay suitable for low-intensity mooring operations.
- Good geographical position along WAC2 and proximity to regional logistics flows.

Limitations:

- No renewable-energy systems (solar or wind) are present.
- No container-handling equipment, preventing ZESpack movement.
- No charging infrastructure or potential for immediate upgrade without major investment.

Role in the AUTOFLEX network: A terminal at Leiden is currently a non-operational Stow&Charge location and would require substantial infrastructure development to participate in the AUTOFLEX energy network. Its function remains limited to vessel transit or emergency mooring rather than battery-exchange or energy services.

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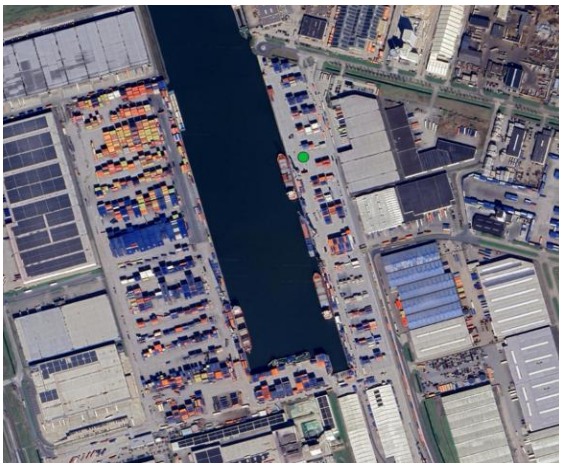
6.5.17. MOERDIJK



Location: Moerdijk (CCT)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-17: Analysis for a potential Stow&Charge hub in Moerdijk
Maps data: © 2025 Google | © 2025 Airbus

A potential terminal at Moerdijk is one of the strongest Stow&Charge candidates in the entire AUTOFLEX network. With full renewable-energy integration (wind and solar), complete battery-logistics capability (BCs + CHE) and established or easily expandable charging infrastructure, it meets every criterion for Level 4, the highest level in the classification matrix.

Strengths:

- Extensive solar and wind-energy production enables high renewable-energy autonomy.
- Large terminal area with ample space for ZESpack logistics, charging zones and future expansion.
- Strong industrial grid connection typical of the Moerdijk port cluster, supporting high-capacity charging.
- Full container-handling infrastructure ensures efficient BC movement and vessel turnaround.
- Excellent intermodal connectivity (road, rail, water), making it a central logistics node.

Limitations:

- High utilisation may require careful zoning to integrate large-scale SCH operations.
- Renewable-energy output may require buffering strategies to handle peak operational loads.

Role in the AUTOFLEX network: A terminal at Moerdijk functions as a primary Tier-1 Stow&Charge hub. Its combination of large area, strong grid access and renewable-energy capacity ensures it can supply multiple corridors and serve as a major ZESpack distribution center. This terminal is uniquely well-suited for scaling fully electric inland navigation in the region.

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6.5.18. NIJMEGEN

Location: Nijmegen	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-18: Analysis for a potential Stow&Charge hub in Nijmegen
Maps data: © 2015-2025 Google | © 2015-2025 Data SIO | © 2015-2025 NOAA | © 2015-2025 U.S. Navy | © 2015-2025 NGA | © 2015-2025 GEBCOLandsat / Copernicus

A potential terminal at Nijmegen qualifies as a Level 4 facility, indicating full readiness for Stow&Charge operations and complete alignment with the highest standards defined in the matrix. The terminal benefits from both major forms of renewable-energy generation—solar and wind—while also providing the full suite of ZESpack-related operational capabilities, including charging stations, battery-container handling and comprehensive container-handling equipment.

Strengths:

- Full renewable-energy integration (wind + solar) supports strong energy autonomy and resilience.
- Complete ZESpack logistics functionality (CSs + BCs + CHE) ensures seamless battery-exchange and charging operations.
- Strategic location on the Waal corridor, serving as a major inland gateway between the Netherlands and Germany.
- Infrastructure scale and multimodal connectivity enable high-throughput and robust operational performance.

Limitations:

- High utilisation typical of large river terminals may require dedicated zoning for Stow&Charge operations.
- Integration of renewable-energy management with grid load-balancing may require advanced energy-management systems.

Role in the AUTOFLEX network: A terminal at Nijmegen functions as a Tier-1 Stow&Charge hub, enabling long-distance electric navigation between the Dutch core network and cross-border corridors. With its Level 4 feature set, it is ideally suited to supply large-volume traffic and serve as a backbone node for future autonomous and zero-emission inland-shipping services.

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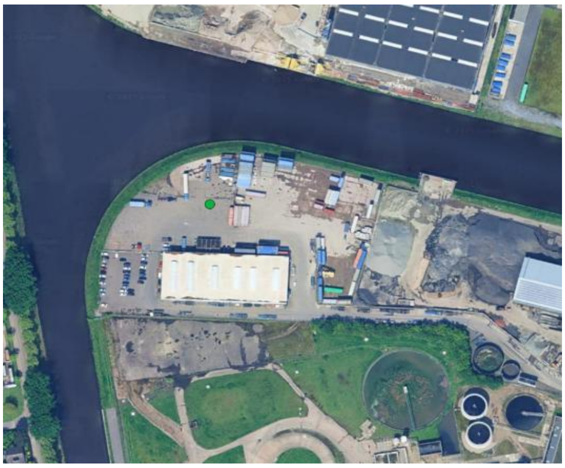
6.5.19. ROOSENDAAL



Location: Roosendaal	
Container Handling Equipment (CHE)	✗
ZES Battery Containers (BCs) feasible	✗
ZES Charging Station (CS) feasible	✗
Solar-based Energy Production (SEP)	✓
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 0	

Figure 6-19: Analysis for a potential Stow&Charge hub in Rosedaal
Maps data: © 2024 Google

A potential terminal at Rosedaal falls under Level 0, as it lacks nearly all core capabilities required for Stow&Charge operations. Although limited solar-energy production is present, this alone is insufficient to support energy-enabled inland-vessel logistics. The absence of charging infrastructure, battery-container handling capability and container-handling equipment prevents the terminal from functioning as an operational node within the AUTOFLEX energy network.

Strengths:

- Presence of solar-energy systems provides a minimal foundation for future renewable-energy development.
- Geographical placement along regional transport corridors offers potential long-term relevance.

Limitations:

- No charging infrastructure for ZESpacks.
- No BC handling capability or container-handling equipment.
- Renewable integration is minimal and insufficient to support SCH operations.

Role in the AUTOFLEX network: A terminal at Rosedaal currently serves as a non-operational location from an energy-logistics perspective. While the presence of solar energy presents some future upgrade potential, significant investment in infrastructure—CHE, CSs and BC handling—would be necessary before the terminal could be considered a functional Stow&Charge node.

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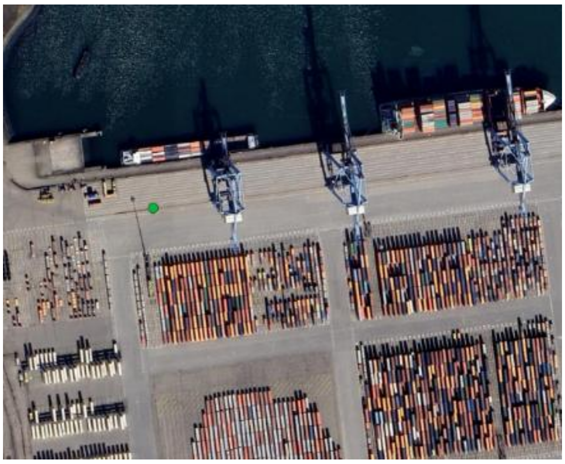
6.5.20. ROTTERDAM – EUROPAHAVEN



Location: Rotterdam (Europahaven)	
Container Handling Equipment (CHE)	✓
ZES Battery Containers (BCs) feasible	✓
ZES Charging Station (CS) feasible	✓
Solar-based Energy Production (SEP)	✗
Wind-based Energy Production (WEP)	✓
Stow&Charge Hub level (potential) = 3-4	

Figure 6-20: Analysis for a potential Stow&Charge hub in Rotterdam- Europahaven
Maps data: © 2025 Google | © 2025 Airbus

A potential terminal at Rotterdam–Europahaven qualifies as a Level 3 facility. The presence of wind-energy production, combined with full charging capability (CSs) and comprehensive battery-container logistics (BCs + CHE), positions the terminal as an advanced energy-enabled node. Although the site lacks solar-energy integration, its combination of renewable wind power and strong operational capacity ensures high readiness for Stow&Charge operations. Adjacent to the terminal is the Maasvlakte power plant, which supplies about 7% of the Netherlands electricity. While energy produced at the power plant is not zero-emission, it underlines the high capacity of the grid which this terminal is connected to. In a sense, it could be considered to be level 4 with the high capacity grid, although the energy mix would include coal based electricity.

Strengths:

- On-site or adjacent wind-energy production provides renewable-energy autonomy.
- Full ZESpack handling, storage and charging capability.
- Embedded within Rotterdam's heavy-duty intermodal cluster, ensuring high throughput and resilience.
- Adjacent to a major power plant and has high capacity grid. Ensures robust supply.

Limitations:

- No solar-energy installations, limiting the diversity of renewable-energy sources.
- Space allocation for future expansion may depend on high terminal utilisation.

Role in the AUTOFLEX network: A terminal at Rotterdam-Europahaven is a strategic Stow&Charge hub within the Rotterdam system and a natural high-capacity support point for long-range inland corridors. Its Level-3 capability makes it suitable for frequent ZESpack exchange operations, with potential to reach Level 4 should additional zero-emission production be established.

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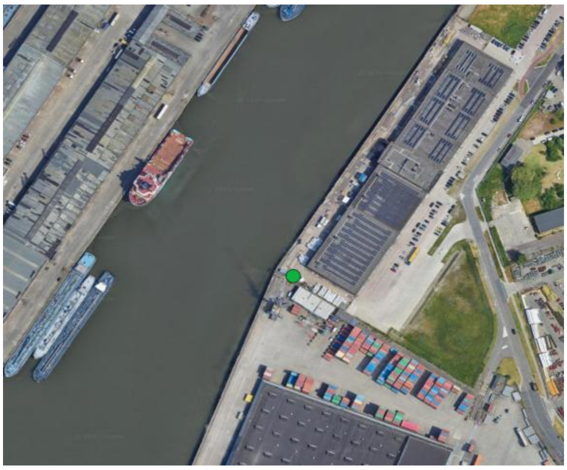
6.5.21. ROTTERDAM – MATHENESSE



Location: Rotterdam (Mathenesse)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✘
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 2	

Figure 6-21: Analysis for a potential Stow&Charge hub in Rotterdam-Mathenesse
Maps data: © 2023 Google

A potential terminal at Rotterdam–Mathenesse qualifies as a Level 2 site. It provides full operational capability for handling containers and BCs, and CS could feasibly be established. However, the absence of solar and wind-energy generation limits the terminal's autonomy and constrains its ability to function as a renewable-energy hub.

Strengths:

- Fully capable of handling ZESpacks (BCs).
- CS could feasibly be established
- Strong container-handling infrastructure (CHE), typical of Rotterdam terminals.
- Strategically embedded within the Port of Rotterdam logistics cluster, enabling high throughput and connectivity.

Limitations:

- No on-site renewable-energy production (no solar or wind installations observed).
- Limited potential for local energy autonomy without grid reinforcement or future renewable integration.

Role in the AUTOFLEX network: A terminal at Mathenesse serves as a high-capacity operational Stow&Charge terminal, ideal for frequent vessel turnaround and battery exchange. Its strong logistical position compensates for the lack of on-site renewable-energy systems. With the introduction of solar installations, the terminal could progress toward Level 3 (or higher, eventually).

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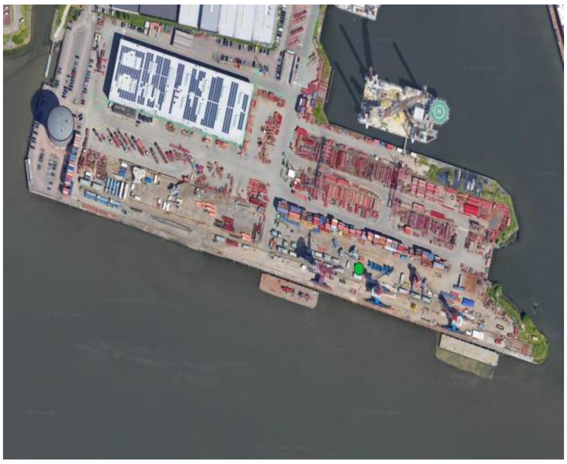
6.5.22. ROTTERDAM – VLAARDINGEN



Location: Rotterdam (Vlaardingen)	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 3	

Figure 6-22: Analysis for a potential Stow&Charge hub in Rotterdam-Vlaardingen
Maps data: © 2021 Google

A potential terminal at Rotterdam–Vlaardingen qualifies as a Level 3 terminal, indicating strong readiness for Stow&Charge operations. The presence of solar-energy production and full ZESpack-handling capability being feasible (charging, storage and container movement) positions Vlaardingen as one of the more advanced terminals in the Rotterdam region. Although the site lacks wind-energy integration, it still offers substantial operational autonomy and high-throughput capability.

Strengths:

- Solar-energy installations support partial renewable self-sufficiency.
- Full operational capability for ZESpack logistics feasible: charging, handling and storage.
- Located within the Port of Rotterdam cluster, ensuring strong intermodal connectivity and high operational capacity.

Limitations:

- No wind-energy production reduces renewable diversity and limits maximum on-site energy autonomy.
- Expansion potential may depend on terminal layout and local industrial constraints.

Role in the AUTOFLEX network: A terminal at Rotterdam-Vlaardingen functions as a high-value Stow&Charge node, supporting major corridor flows and offering reliable charging and logistics operations. Its Level 3 profile makes it a key location for energy-enabled inland shipping within the broader Rotterdam system.

Funded by the European Union

6.5.23. SCHIPHOL

Location: Schiphol	
Container Handling Equipment (CHE)	✕
ZES Battery Containers (BCs)	✕
ZES Charging Station (CS)	✕
Solar-based Energy Production (SEP)	✕
Wind-based Energy Production (WEP)	✕
Stow&Charge Hub level (potential) = 0	

Figure 6-23: Analysis for a potential Stow&Charge hub in Amsterdam-Schiphol
Maps data: © 2023 Google | © 2023 Vexcel Imaging US, Inc.

A potential terminal at Schiphol qualifies as a Level 0 site. Despite its strong role within the broader Amsterdam logistics ecosystem, the terminal lacks the essential components required for supporting Stow&Charge operations. There are no local renewable-energy installations, no charging infrastructure, no battery-container handling capacity and no visible container-handling equipment.

Strengths:

- Good road accessibility and regional connectivity.
- Proximity to major logistics flows linked to the Schiphol airport area.

Limitations:

- No renewable-energy generation (solar or wind) visible on-site.
- No ZESpack charging or handling infrastructure.
- No container-handling equipment, limiting any form of cargo-energy interaction.

Role in the AUTOFLEX network: A terminal at Schiphol currently plays no functional role within the Stow&Charge energy network and can be considered a non-operational point from the perspective of battery-electric inland shipping. Significant, multi-stage upgrades would be required for any future transition toward a higher level.

Funded by the European Union

6.5.24. 'S-HERTOGENBOSCH

Location: 's-Hertogenbosch	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs)	✔
ZES Charging Station (CS)	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✔
Stow&Charge Hub level (potential) = 4	

Figure 6-24: Analysis for a potential Stow&Charge hub in 'S-Hertogenbosch
Maps data: © 2024 Google

A potential terminal in 's-Hertogenbosch qualifies as a Level 4 facility, demonstrating the highest level of readiness for Stow&Charge operations within the AUTOFLEX framework. The terminal integrates both major renewable-energy sources—wind and solar—while also providing full operational capability for ZESpack logistics, including charging infrastructure, battery-container handling and container-handling equipment.

Strengths:

- Full renewable-energy integration (wind + solar), enabling strong on-site energy autonomy.
- Complete operational capability for ZESpack handling, charging and storage.
- Strategically positioned along important inland-shipping routes.
- Well-developed logistics environment supports high-throughput operations.

Limitations:

- High utilisation may necessitate dedicated zoning for large-scale energy-logistics operations.
- Grid-load management may require optimisation during peak renewable-energy production periods.

Role in the AUTOFLEX network: A terminal at 's-Hertogenbosch serves as a Tier-1 Stow&Charge hub, ideally positioned to support continuous flows along multiple WACs. Its Level 4 status makes it one of the most capable inland nodes for large-scale electrified shipping operations.

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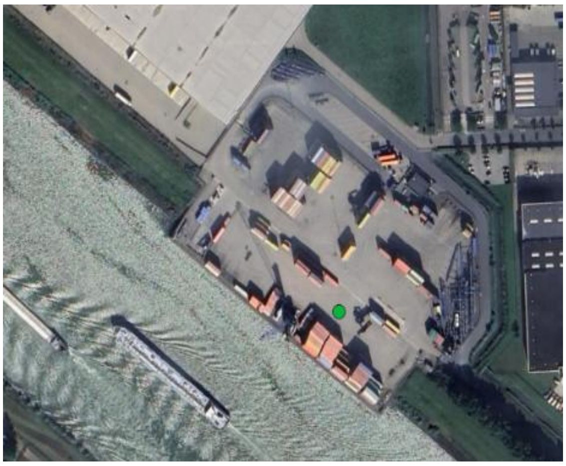
6.5.25. TIEL



Location: Tiel	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✘
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 1	

Figure 6-25: Analysis for a potential Stow&Charge hub in Tiel
Maps data: © 2025 Google | © 2025 Airbus

A potential terminal at Tiel is classified as a Level 1 site. Although limited solar-energy production is present and basic container-handling equipment (CHE) is available, the terminal lacks all essential components for Stow&Charge operation. However, given its activities as a container terminal today, Tiel may be able to integrate battery containers (BCs) into its operation and through this begin its electrification journey. However, the absence of charging infrastructure (CSs) prevents Tiel from participating in more advanced forms of energy-enabled inland-shipping processes.

Strengths:

- Presence of solar-energy systems offers a minimal starting point for future renewable integration.
- CHE availability supports basic cargo operations and could facilitate future upgrades.
- Useful location along a regional inland corridor.

Limitations:

- No ZESpack charging capability.
- No ability to handle or store battery containers.
- Renewable-energy presence is insufficient for supporting charging loads.
- Limited overall infrastructure restricts scalability.

Role in the AUTOFLEX network: A terminal at Tiel currently serves as a non-operational Stow&Charge location, suitable only for basic vessel calling and conventional cargo movement. To become a functional Level 2 site, Tiel would require the installation of charging infrastructure and expanded energy integration, which may be impossible but perhaps challenging given its small size and consequent spatial constraints.

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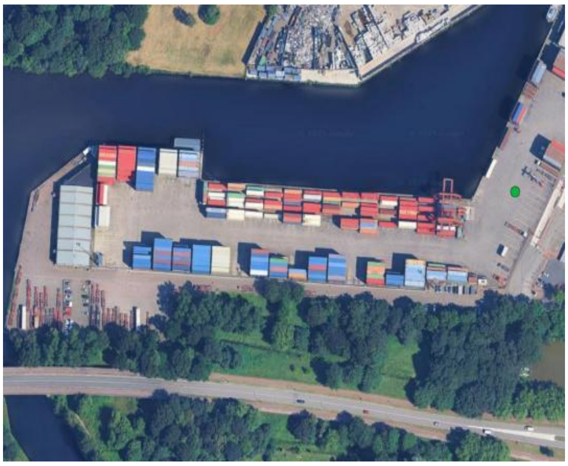
6.5.26. TILBURG



Location: Tilburg	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✗
Stow&Charge Hub level (potential) = 3	

Figure 6-26: Analysis for a potential Stow&Charge hub in Tilburg

A potential terminal at Tilburg qualifies as a SCH Level 3 Stow&Charge-capable facility. The presence of solar-energy production, feasibility of full ZESpack-handling capability (BCs + CHE) and operational charging infrastructure (CSs) ensures a high level of readiness for integrating battery-electric inland vessels. Although the terminal lacks wind-energy production, the combination of solar power and strong operational capacity provides partial energy autonomy.

Strengths:

- Solar-energy generation enables partial renewable-energy coverage for charging.
- Fully equipped for ZESpack logistics: charging, handling and container operations.
- Located within the Breda–Tilburg–Waalwijk logistics corridor, providing strong multimodal integration.

Limitations:

- No wind-energy production reduces renewable diversity.
- Terminal expansion may be limited depending on industrial land-use constraints.

Role in the AUTOFLEX network: A terminal at Tilburg acts as a high-value secondary Stow&Charge terminal along central Dutch corridors. Its Level 3 classification enables reliable charging and battery-exchange operations, making it a strong mid-network support point with the potential to evolve toward SCH Level 4 through additional renewable-energy integration.

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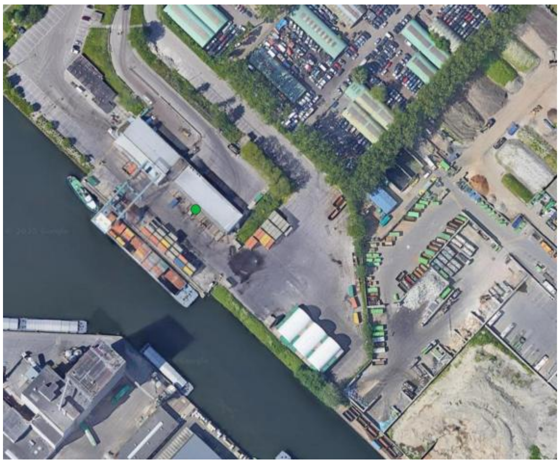
6.5.27. UTRECHT



Location: Utrecht	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✔
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 3	

Figure 6-27: Analysis for a potential Stow&Charge hub in Utrecht
Maps data: © 2021 Google

A potential terminal at Utrecht qualifies as a Level 3 facility, reflecting its strong operational and energy-integration potential. The terminal is equipped with solar-energy production, charging infrastructure and full battery-logistics capability is feasible (BCs + CHE). These elements enable active participation in the Stow&Charge network and provide a high level of operational autonomy.

Strengths:

- Solar-energy installations support partial renewable self-sufficiency.
- Full capability set for ZESpack handling, charging and storage is feasible.
- Strong logistical role in the central Netherlands, positioned at a key corridor intersection.

Limitations:

- No on-site wind-energy production, limiting renewable diversity.
- Expansion potential may be constrained by surrounding industrial-urban development.

Role in the AUTOFLEX network: A terminal at Utrecht could perform as a major secondary Stow&Charge hub, bridging northern and southern network segments. Its Level 3 features make it ideal for high-frequency ZESpack exchange and energy redistribution along WAC1 and WAC2. With the addition of wind-energy capacity, the terminal could progress toward Level 4 in the future.

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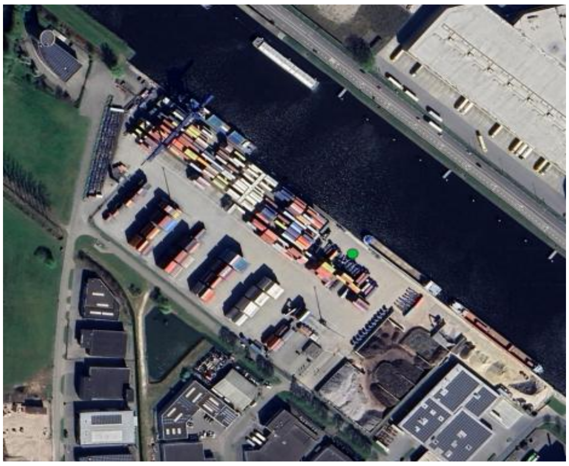
6.5.28. VEGHEL



Location: Veghel	
Container Handling Equipment (CHE)	✔
ZES Battery Containers (BCs) feasible	✔
ZES Charging Station (CS) feasible	✔
Solar-based Energy Production (SEP)	✘
Wind-based Energy Production (WEP)	✘
Stow&Charge Hub level (potential) = 2	

Figure 6-28: Analysis for a potential Stow&Charge hub in Veghel
Maps data: © 2025 Google | © 2025 Airbus

A potential terminal at Veghel qualifies as a Level 2 facility. While it does not currently integrate renewable-energy production (solar or wind), the terminal is fully capable of supporting ZESpack operations thanks to the presence of charging stations, battery-container handling capability and container-handling equipment. This makes it a functional Stow&Charge point with reliable operational performance.

Strengths:

- Fully capable of ZESpack handling, charging and logistical operations.
- Strong operational integration within the Veghel–Den Bosch–Eindhoven industrial corridor.
- Suitable quay infrastructure and adequate space for SCH activities.

Limitations:

- No renewable-energy production limits energy autonomy and environmental benefits.
- Reliance on grid-supplied electricity may constrain long-term scalability.

Role in the AUTOFLEX network: A terminal in Veghel serves as a mid-corridor operational Stow&Charge terminal, essential for supporting ZESpack-based vessel operations along central Dutch inland routes. With the future integration of solar or wind energy, Veghel could progress toward Level 3.

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6.6 RECOMMENDATIONS FOR STOW&CHARGE NETWORK ARCHITECTURE

After the analysis of potential Stow&Charge Hubs (SCHs), the whole operational route network was evaluated in terms of identifying potential stow and charge hubs as well as necessary infrastructure gaps. The following synthesis evaluates each operational corridor individually, integrating both the technical capability level (i.e. the SCH level ranging from 0-4) and the operational relevance of each terminal.

6.6.1. SYNTHESIS OF POTENTIAL STOW&CHARGE LOCATIONS

WAC1:

This corridor connects Amsterdam with Utrecht and includes a mixture of high-density port environments and regional terminals. SCH-level assessment indicates:

- **Amsterdam – Holland Cargo Terminal (SCH-4)** functions as the northern anchor hub with full renewable-energy integration and high throughput capacity.
- **Haarlem (SCH-0)** and **Schiphol (SCH-0)** provide no meaningful SCH capability.
- **Leiden (SCH-0)** and **Gouda (SCH-1)** offer limited operational or renewable-based support potential.
- **Utrecht (SCH-3)** acts as a southern high-capability node with solar integration and full handling capacity.

The corridor features a **dual-hub structure** with Amsterdam (SCH-4) and Utrecht (SCH-3) as the only viable candidates for SCH operations. All intermediate terminals lack the infrastructure required to support battery-electric vessel operations. Energy supply along the route must therefore rely on these two hubs, with Utrecht performing mid-corridor functions and Amsterdam acting as the main charging and distribution point.

The corridor topology suggests a two-node SCH model, enabling reliable round-trip operations through strategic ZESpack exchange at Amsterdam and Utrecht.

WAC2:

This corridor links a diverse set of terminals from Alkmaar down to ’s-Hertogenbosch.

- **Alkmaar (SCH-0)**, **Leiden (SCH-0)**, **Den Haag (SCH-1)** offer very limited capability.
- **Gouda (SCH-1)** provides minimal operational potential.
- **Utrecht (SCH-3)** serves as a high-capacity mid-corridor node.
- **’s-Hertogenbosch (SCH-4)** is the most capable terminal on the route.

The corridor has a clear north–south capability gradient, with almost no energy-enabled terminals in the northern section. The corridor effectively depends on:

1. **Utrecht (SCH-3)** as the operational consolidation point
2. **’s-Hertogenbosch (SCH-4)** as the primary southern SCH hub

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Intermediate terminals are unsuitable for regular SCH functions and would require extensive upgrades to support battery operations.

Energy availability along the WAC2 is highly asymmetric, and SCH infrastructure should be concentrated at Utrecht and ’s-Hertogenbosch, enabling controlled battery logistics despite low-capability segments.

WAC3:

This corridor traverses the industrial heart of the southern Netherlands.

- **Rotterdam Europahaven (SCH-3)** and **Rotterdam Vlaardingen (SCH-3)** serve as northern operational hubs.
- **Rotterdam Mathenesse (SCH-2)** adds charging and handling capability but lacks renewables.
- **Dordrecht (SCH-2)** forms a strong inland operational node.
- **Moerdijk (SCH-4)** is the central, highest-capability hub of the entire region.
- **Breda (SCH-3)** and **Tilburg (SCH-3)** function as strong mid-corridor terminals.

The corridor exhibits the most robust and continuous SCH coverage among all corridors. With multiple SCH-2 and SCH-3 terminals and the Tier-1 hub at Moerdijk, the corridor forms a dense energy-enabled cluster capable of supporting:

- high-frequency operations
- long-range battery logistics
- scalable energy-distribution flows

The corridor should be considered the **primary backbone corridor** for large-scale AUTOFLEX deployment, with Moerdijk serving as the energy distribution centre and Tilburg/Breda/Dordrecht acting as operational relay nodes.

WAC4:

This corridor connects high-capability and low-capability nodes.

- **Nijmegen (SCH-4)** acts as a major gateway hub.
- **Arnhem (SCH-0)** offers no capability.
- **Tiel (SCH-0)** also offers no capability.

The corridor is extremely asymmetric, with one strong terminal (Nijmegen) and two minimal-capability nodes. All SCH operations along this corridor must be conducted exclusively at Nijmegen.

Battery exchange and charging capability is fully centralized, meaning energy availability along the route depends entirely on the performance and capacity of Nijmegen.

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WAC5:

The corridor is significantly influenced by industrial zones and mid-sized terminals.

- **Moerdijk (SCH-4)** serves as the northern anchor hub.
- **Veghel (SCH-2)** provides full operational functionality without renewables.
- **Helmond (SCH-3)** includes solar integration and full ZESpack capability.
- **Eindhoven (SCH-0)** lacks operational capacity and cannot support cargo and energy operations.

The corridor features a **two-tier structure**:

- **Moerdijk** and **Helmond** act as strong SCH nodes
- **Veghel** serves as a mid-corridor operational terminal
- **Eindhoven** contributes no value to the Stow&Charge network

Moerdijk and Helmond should be prioritized for coordinated SCH infrastructure, with Veghel supporting throughput but requiring renewable integration for long-term viability.

6.6.2. POTENTIAL STOW&CHARGE NETWORK ARCHITECTURE

Based on the SCH-Level assessment, corridor synthesis and the operational requirements of the AUTOFLEX vessel, a prioritized Stow&Charge Hub (SCH) network architecture can be defined. The objective is to identify locations where investment in charging infrastructure, renewable integration or operational upgrades yields the highest system-wide impact.

The recommended network distinguishes between **primary** (Tier-1) hubs, **secondary** (Tier-2) hubs and **supporting** terminals.

The hub characterisation depends on the following criteria:

- SCH-Level maturity (Level 3–4 preferred)
- Corridor centrality & vessel frequency
- Availability of renewable energy (wind/solar)
- Existing charging infrastructure or upgradeability
- Terminal size, operational throughput and available space
- Grid access for high-power charging (≥ 1 MW)
- Role in connecting multiple corridors
- Strategic value for long-distance battery logistics

Terminals meeting multiple criteria provide the highest leverage for deployment and network resilience.

Tier-1 Stow&Charge hubs (primary nodes) are essential for the core AUTOFLEX energy network. These terminals are major energy-logistics centres that support:

- high-frequency ZESpack exchange,

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- large energy-storage volumes,
- full renewable integration,
- and corridor-spanning battery redistribution.

The following terminals have been selected for Tier-1 Hubs:

- **Moerdijk (SCH Level 4):** A central industrial-energy cluster with full renewable-energy production, strong grid capacity and extensive handling infrastructure. Primary function: National energy-distribution node and corridor backbone.

- **Nijmegen (SCH Level 4):** Major inland gateway on the Waal with full operational capability and renewable integration. Primary function: Eastern energy gateway and cross-border electrification anchor.

- **'s-Hertogenbosch (SCH Level 4):** High-capacity terminal with large operational footprint and complete renewable portfolio. Primary function: Southern green Route hub with strong multimodal connectivity.

- **Amsterdam – Holland Cargo Terminal (SCH Level 4):** Strategic northern hub with high throughput and full wind/solar integration. Primary function: Northern anchor hub and launch point for the WAC1.

- **Ghent (DFDS) (SCH Level 4):** Large-scale industrial port with complete SCH capability and cross-border logistics relevance. Primary function: Belgian anchor hub and energy logistics consolidation point.

These Tier-1 hubs form the energy backbone of the AUTOFLEX system, supporting long-range vessel operations, stabilizing energy distribution and enabling scaling of ZESpack logistics.

Tier-2 Stow&Charge hubs (secondary nodes) support Tier-1 terminals by offering corridor accessibility and operational redundancy. They are suitable for:

- regional charging,
- secondary ZESpack handover points,
- contingency routing,
- and corridor densification.

The following terminals have been selected for Tier-2 Hubs:

- **Utrecht (SCH Level 3):** Key intersection of multiple routes; solar integration and full handling capability.

- **Rotterdam – Europahaven (SCH Level 3):** Strong operational node with wind-energy potential and excellent intermodal infrastructure.

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- **Rotterdam – Vlaardingen (SCH Level 3):**
  High-capacity terminal supporting both inland and coastal flows.

- **Breda (SCH Level 3):**
  Mid-corridor support hub with solar production.

- **Tilburg (SCH Level 3)**
  Strong central Netherlands hub for container and energy flows.

- **Helmond (SCH Level 3)**
  Operational node on the Orange Route with solar integration.

- **Antwerp – Albertkanaal (SCH Level 3)**
  Important Belgian corridor hub with high throughput and charging capability.

- **Antwerp – Graandok (SCH Level 3)**
  Fully equipped operational support terminal for inland and short-sea vessels.

- **Antwerp – MSC PSA (SCH Level 3)**
  Large-scale strategic terminal with wind integration and full logistics capability.

These terminals significantly enhance **network resilience**, allow **energy buffering**, and reduce dependency on Tier-1 hubs by distributing charging capacity across the network.

The third category of the network are supporting terminals that currently provide minimal or no SCH functionality, but may still serve as:

- vessel mooring points,
- emergency fallback locations,
- or future candidates for incremental upgrades.

Based on these criteria the following terminals have been selected for supporting hubs:

- Rotterdam – Mathenesse (SCH Level 2)
- Dordrecht (SCH Level 2)
- Veghel (SCH Level 2)

These terminals can already perform operational ZESpack handling and charging but lack renewable energy and long-term scalability. They may be upgraded selectively if required by corridor demand.

- Alkmaar (SCH Level 0-1)
- Leiden (SCH Level 0-1)
- Schiphol (SCH Level 0-1)
- Haarlem (SCH Level 0-1)
- Den Haag (SCH Level 0-1)

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- Gouda (SCH Level 0-1)
- Rosedaal (SCH Level 0-1)
- Eindhoven (SCH Level 0-1)
- Arnhem (SCH Level 0-1)
- Tiel (SCH Level 0-1)

These terminals lack critical infrastructure such as charging stations, CHE or renewable-energy integration. They are not recommended for SCH investments without significant redevelopment.

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7 MOBILE DISTRIBUTION CENTRES

7.1 INTRODUCTION

Decaying traditional markets of IWT, e. g., dry bulk transport, pose a threat to the state of the IWT industry and its stakeholders. Previous market equilibria are being shaken up, business areas and models must face up to change and assert themselves through adaptation. Next to new cargoes such as hydrogen and ammonia in conjunction with some new transport relationships, the use of small inland waterway vessels on shorter routes in urban, local and regional transport concepts is attracting considerable attention in both academia and industry. Only in exceptional cases will this involve new bulk transport in the traditional style, i. e., the production of the cargo and the loading of the vessel directly in a port on the inland waterway, transport by water and unloading directly in a port on the waterway, followed by consumption directly on site. Instead, inland waterway vessels will be integrated into new intermodal transport concepts, as the locations of freight generation and consumption are often far away from inland waterways. Accordingly, the transport system must employ additional transport legs for the first and last mile from and to the customer. However, this requires various adjustments to the components of a future transport system and, in some cases, the development of new solutions to close existing gaps, especially in view of the emerging trend towards automation of ship operations. In view of the expected shift away from long-distance transport and the focus on short and medium-distance transport, adjustments to goods are also necessary – both in terms of load volume and types of goods. Whereas full vessel loads (FVL) are the usual standard regarding inland waterway transport, particularly in long-distance bulk cargo transport, less-than-full vessel loads (LVL) are typically characteristic to inland waterway container transport with its liner services to pick up and deliver individual containers along the route. However, a split of the cargo on transport unit level, as is usual in road transport and sea transport, is not foreseen in inland waterway transport to date as it requires the additional step of cargo consolidation. Cargo consolidation is crucial, especially for sustainable modes of transport with limited return transport options, such as IWT, but oftentimes fails due to infrastructural, temporal, and commercial challenges. Therefore, new forms of consolidation concepts must be explored that go beyond traditional sorting and cross-docking models and potentially enable multiple transport customers to share segmented container space at the loading and unloading locations.

7.2 METHODOLOGY

Since the task encompasses the identification of the gaps withstanding the generation of a future transport system, the design and development of suitable solutions, and eventually their demonstration, a series of alignment meetings and workshops to develop the right parameters and to select the right choices, and several surveys in order to gather ideas and opinions have been conducted – both with the external experts and stakeholders and a project-internal group consisting of experts in transport engineering, naval architecture, logistics management, mechanical engineering, cybernetics, and industrial engineering from six organisations from both industry and academia. Chapter 7.4 describes the evolutionary design and development stages of the solution concept development process.

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The iterative approach enabled the group to review their latest decisions, adjust them if necessary, and use them as a basis for the next step in the research and development process. This made it possible to largely avoid or even rule out hasty decisions and potential conflicts that could have arisen as a result.

As part of the idea collection process and after the initial solution design, mock-ups have been used to convey the idea of the alternative concepts and solutions per decision item. In general, mock-ups are used as design tools almost everywhere where a new product is being designed, and they are an effective means of obtaining feedback from potential users, particularly about design and configuration choices as well as usability and performance estimations. Eventually, the final demonstrator, which is built and presented in the HaFoLa Port Research Lab of DST in Duisburg, Germany, is a real-scale mock-up model of the envisioned concept, facilitating the assessment of the final concept and its precise configuration. For the involved group members, the final demonstrator is a way to safeguard their joint choices have been implemented effectively, comprehensively, and correctly.

7.3 BACKGROUND

7.3.1. PROBLEM STATEMENT

Road transport is characterised by congestion, delays, emissions, and poor performance indicators. As discussed in Section 3.3 , truck load factors are often low, and empty runs are common. Numerous past and ongoing initiatives have aimed to address this issue by increasing volume density per transport unit. However, underutilisation is not unique to road transport; inland waterway transport (IWT) also experiences capacity waste due to empty or partially loaded containers, although precise utilisation data are scarce. Road transport additionally absorbs a large share of empty container repositioning, a costly and complex task for carriers. This situation is exacerbated by imbalances in global freight transport, reflected in uneven cargo flows and utilisation rates between export-oriented and consumption-driven economies. These conditions directly affect both road transport and IWT operations.

Cargo consolidation of transport assets (e. g., trucks or vessels), transport units (e. g., trailers, containers, or pallets), and transport bins (e. g., boxes or crates) can improve logistics resource utilisation and reduce environmental impacts. In IWT, however, consolidation must be paired with high and balanced route utilisation, as road transport can more easily optimise return trips at marginal cost. While consolidation can reduce inefficiencies in IWT, it requires strategically located hinterland facilities at the convergence of major cargo flows, such as along key freight corridors. Potential benefits must also outweigh drawbacks, including longer consolidation times, limited suitability for just-in-time or same-day deliveries, and challenges in combining heterogeneous cargo types. The effectiveness of consolidation strongly depends on geographic location, shipment distance, cargo characteristics, urgency, load factors, and the share of less-than-container-load shipments. Moreover, improved coordination between deep-sea terminal operators and inland shipping operators is essential to make hinterland consolidation efficient, a challenge that similarly affects regional, local, and urban transport concepts, where effective consolidation remains rare.

In conclusion, cargo consolidation is vital — especially for sustainable modes with limited backhaul options such as IWT — but often fails due to infrastructural, timing, and commercial constraints. New approaches are therefore needed that move beyond traditional cross-docking and enable multiple shippers to share segmented container capacity directly at loading and unloading points.

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7.3.2. SOLUTION SPACE

To strengthen short- and medium-distance waterborne transport services, novel part-load consolidation concepts that go beyond traditional sorting and cross-docking and open up new markets are needed. Any potential solution must fulfil several key prerequisites.

Historically, inland waterway transport — especially in Western and Central Europe — typically involved inland vessels serving only a single customer, a practice that still largely persists in bulk cargo segments. In contrast, in convoy operations (push, tow, or coupled units), a single shipper may already handle freight for several different customers, with each pushed or towed barge allocated to a separate client. For motor cargo vessels, the LVL concept, where shippers reserve only part of a vessel's capacity (or individual slots on board) instead of chartering the entire vessel, is a relatively recent innovation, predominantly in Western and Central Europe but not limited to this region. The use of ISO containers and other standardized loading units has been a key facilitator of this shift, supporting a move away from the traditional focus on bulk transport that historically dominated inland shipping.

A similar idea of mixed loads exists in other transport modes. Ocean shipping distinguishes between full container loads (FCL) and LCL: FCL usually serves a single customer and allows quicker handling, sealing, and customs processing, which reduces costs per unit. LCL combines smaller shipments from various customers, which must be collected and consolidated in facilities such as container freight stations in major ports, so while each customer pays only for their share of capacity, extra handling efforts and costs arise and are passed on to them. Likewise, truck transport differentiates full truck loads (FTL) and less-than-truck loads (LTL): FTL moves cargo for one customer, enabling faster transport, no intermediate sorting, and lower cost per item. LTL merges shipments from multiple customers and needs additional pick-up, delivery, and sometimes sorting or cross-docking, but it is used both for long-distance continental transport and for first- and last-mile legs of maritime shipments.

For intermodal services including IWT legs to match road transport in service depth, an LVL concept should (1) allow swift pick-up and delivery, (2) support additional bundling and sorting steps, and (3) meet typical freight transport constraints. Whereas LCL ignores individual pre- and post-haul legs, LTL covers them via dedicated pick-up and delivery. LVL must work within geographic constraints by minimising truck distance in intermodal services and providing convenient, accessible locations for cargo handling instead of serving every factory ramp. Hence, a small inland vessel navigable on small inland waterways and, thus, with access to a wider network appears a logical complement to the LVL concept. In the context of autonomous inland vessels and promoted modal shift, a developed LVL market could allow small inland vessels in intermodal chains to rival road transport in asset use and unit costs. In order to achieve this, innovations in transport units and assets, which that embed consolidation and cross-docking capabilities in their design rather than relying only on optimised traditional operations, are needed. Thereby, an intermodal LVL concept is truly positioned in direct competition with FTL transport services on the road.

As FTL typically requires an in-field orchestrator, mostly the truck driver, who is responsible for cargo consolidation, last-mile delivery, and cargo distribution, LVL would require an analogous role. Automated inland vessel operations will lack this human role and therefore need substitute solutions via infrastructure, equipment, organisation, and regulation, while business models may push customers to book full units and risk capacity waste, so vehicles,

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units, and service models must preserve the economic and environmental benefits of part-load logistics.

New LVL solutions, especially with IWT where propulsion and cargo space are often integrated and trailers or swap bodies are rare, must use dedicated locations (e. g., ports) to decouple supply and delivery so cargo can be dropped off and collected without fully synchronising with first- and last-mile operators. Decoupling supply and demand is already well known in the transport and logistics domain, typically leading to a shift of responsibility and cost to logistics providers.

An intermodal transport LVL service using small inland vessels must also minimise first- and last-mile legs to customers. To fully exploit the ecological advantage of well-utilised small inland vessels, their share in the transport chain should be maximised while remaining legs are suitable for electric light trucks, electric light commercial vehicles (ELCV), forklifts, and ideally even cargo bikes, as shown in emerging research on such intermodal concepts . The link to existing micro-hubs, city hubs, consolidation depots, or other small, decentralized logistics locations in densely populated urban areas that serves the collection, temporary storage, and last-mile distribution of goods, is obvious.

7.4 EVOLUTION OF MDC DESIGN AND DEVELOPMENT

The market conditions and trends explained above stimulated a structured approach towards the design of an innovative intermodal transport concept footing on SFAZ inland vessels and a sufficiently large network of decentralised transshipment points. This serves to collect and distribute cargo over a shortened distance on the first or last mile, possibly using zero-emission vehicles such as electric trucks, electric vans, or even cargo bikes. In order to realise such a service in a sustainable and viable manner, a missing transport system component needed to be designed and developed in order to open up the market of LVL transport services. The component needs to feature (automated) self-operation by the user, enable a temporal separation between provision (supply) and retrieval (demand), and promote the ecological advantageousness of IWT. The solution concept, the Mobile Distribution Centre (MDC), is defined as a location which is mobile in nature, situated along the inland waterway networks, carrying cargo in smaller transport units, and facilitating adjacent first- and last-mile transport, respectively.

As mentioned above, a project-internal group consisting of experts in transport engineering, naval architecture, logistics management, mechanical engineering, cybernetics, and industrial engineering from six organisations from both industry and academia – along with several external experts and stakeholders – have contributed to the development of an MDC with the help of a series of dedicated workshops, focused surveys, and intensive development sprints in between. Figure 7-1 shows the evolution of steps from setting the scene to developing a final solution concept of an MDC, alternating the workshops (WS) and surveys (S) conducted. Following the initial scoping of the task including problem definition (see section 7.3.1), solution space determination (see section 7.3.2), and reference works collection (see section 7.6), the precise nine-month process started with an on-site workshop of a project-internal core expert group in Duisburg, Germany, in February 2025 and ended with another on-site workshop with the project-internal expert group members and external stakeholders in Hamburg, Germany, in October 2025. The details of the individual stages are explained in the following. In total, eight different stages were completed in order to develop the MDC concept – on six different dates as one on-site workshop and one on-line workshop has been located with a survey each (Alias et al., 2026).

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Figure 7-1. Evolution stages of the design and development process of the Mobile Distribution Centre

In February 2025, a project-internal core group – consisting of representatives from the consortium members DFDS, DST, and SINTEF Ocean – convened on site (WS 1) at the DST premises in Duisburg and reviewed the main purpose of the system component to be designed (see Figure 7-2 and Figure 7-3). The missing component was to facilitate last-mile transport of cargo which has been hauled on small inland waterways to both large inland ports and small, decentralised transshipment points, which may be located in urban centres, industrial parks, or remote transhipment berths in the periphery.

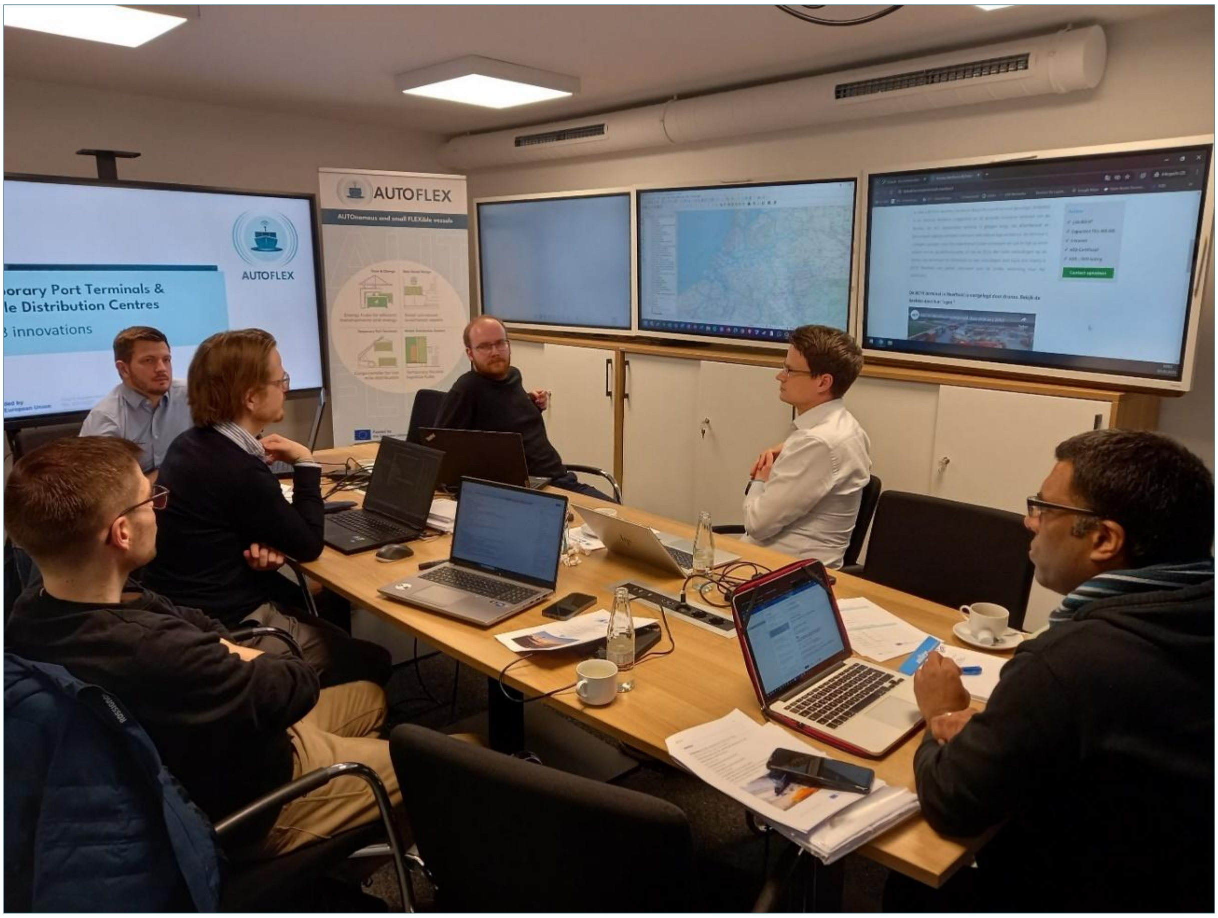

Figure 7-2. Defining the scope of an MDC during WS 1, the initial on-site workshop in Duisburg, Germany

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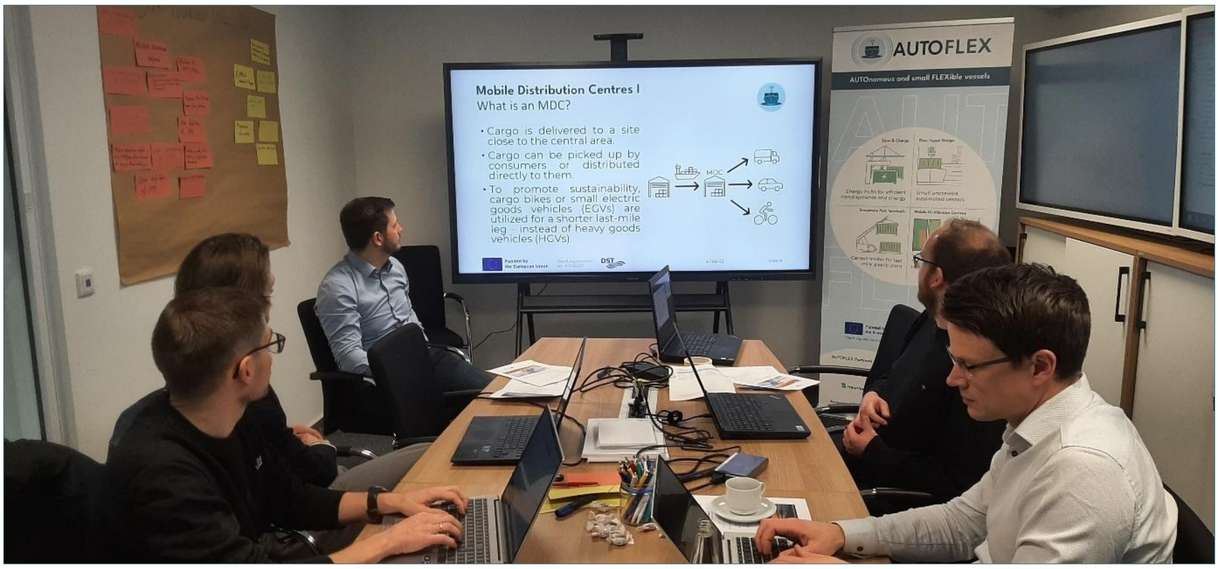

Figure 7-3. Sharing ideas of potential MDC designs during WS 1

Basic questions like the purpose (e. g., for cargo collection, distribution, or both), the form of cargo storage (e. g., in an inland vessel, an ISO container, or in a new receptacle), the destined cargo types, and the number of locations to be equipped with (i. e., one central place or multiple decentralised ones) belonged to the list of discussion items. In addition, the potential integration into so-called micro-scenarios, i. e., potential routes of urban or regional transport cases using the above-mentioned SFAZ inland vessels and land-based vehicles for the adjacent transport leg, were discussed. Apart from limiting the solution space by addressing those questions and collecting the initial ideas, the main result was the decision to collect the most relevant requirements towards such an MDC. Based on the purpose of the MDC defined in the workshop, the subsequent step of concept development was initiated.

In a subsequent survey (S 1), the project-internal expert group has replied to focused questions about the basic purpose and different configuration parameters of the MDC concept (see Figure 7-4). The survey has been set up as an on-line poll during an interactive workshop and encompassed thirteen questions about various aspects of a potential MDC, such as its main function, its ideal form and shape, its functioning principle and its technical principle, its customers and customer segments, users, and stakeholders, the cargo types to cover, the expected effects with respect to traffic, cost, service level as well as its ecological and societal impact.

In the (virtual) workshop immediately following the survey session (WS 2), the (same) entire group of participants was confronted with the individual replies to the revealed survey questions so that controversial remarks could be explained and elaborated upon, discussions held, and refinements made (see Figure 7-5 and Figure 7-6). The discussions and elaborations helped to elevate the quality and clarity of the statements made by the respondents and eventually adopt them as relevant remarks. Ultimately, the basic parameters and requirements were selected both according to quality and quantity criteria. With respect to the main function of an MDC, the collection, storage and distribution of cargo as well as the facilitation of first- and last-mile transport, respectively, belonged to the most common answers, as can be seen in Figure 7-5.

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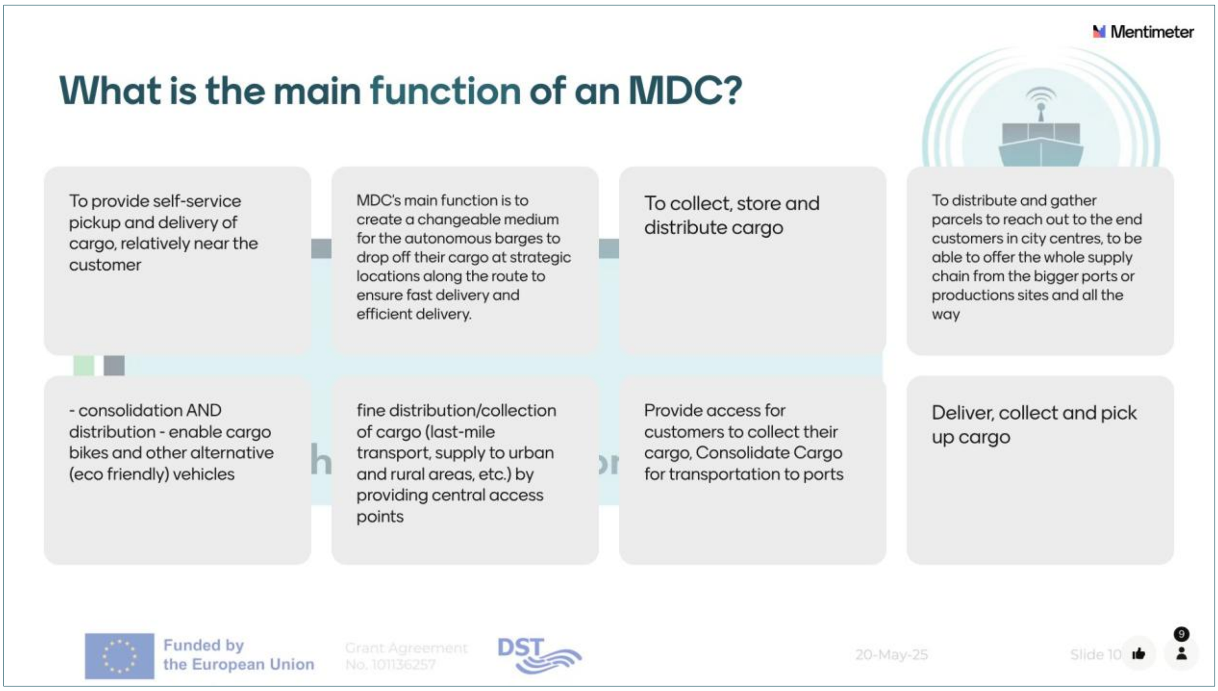

Figure 7-4. Excerpt from the online survey (S 1) on the main function of the MDC

Figure 7-5. Excerpt from the online survey (S 1) on the cargo types to be covered by the MDC

In addition, the self-service character and its flexibility have been emphasised. The MDC is supposed to be a stand-alone object which can be filled with miscellaneous cargo, transported with the help of SFAZ inland vessels, and accessed by users easily in order to pick up cargo from the MDC (or store it in the MDC). The main customers expected to use an MDC are rather commercial than private actors so that the MDC is rather considered to be a B2B than a B2C service. Such commercial actors may be from the manufacturing industry and the retail market but could also include various downtown businesses like convenience stores, restaurants, or product showrooms, and even courier and parcel delivery service providers. Accordingly, potential users are employees of these customer segments as well as of logistics service providers, such as drivers and delivery staff. Further stakeholders envisioned with a role in the MDC service deployment include municipalities and city authorities, port authorities, technology providers, production and supply companies (as potential users), and logistics service providers supposed to collect cargo from the MDC (or deliver it there). Regarding the cargo types, most of the examples shown in Figure 7-6 have been adopted by the respondents. In order to maintain flexibility regarding the industries and customers to serve, a maximally large set of cargo types is expected to be accommodated in the MDC. To these belong pallets, barrels, roll containers, mini-containers vegetable crates, and parcels as well as bulk cargo (in exceptional cases).

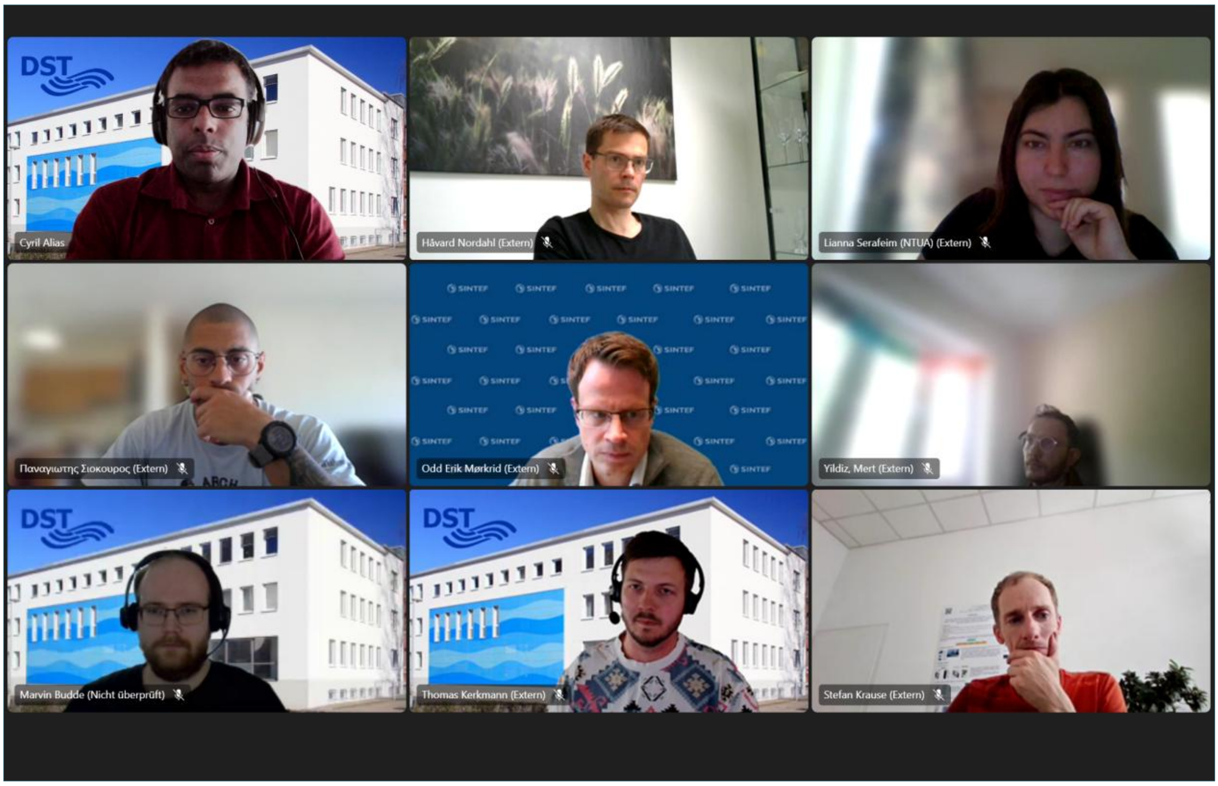

Figure 7-6: Participants of the on-line workshop (WS 2) discussing the basic parameters of the MDC

Related to the preceding question of the functioning principle of the MDC, the ideal form and shape of the MDC is the one of an ISO container – mainly because the SFAZ inland vessel developed in the AUTOFLEX project is a CEMT II inland container vessel and, thus, favours vertical container transshipment. The technical principle behind the MDC foresees a single point of loading and multiple points of retrieval. Hence, the MDC is supposed to feature separate doors to individual compartments within the container – to cater for the LVL service idea. Further, it needs to provide its own energy, an intuitive user interface, an access control system, and a secure design preventing unauthorized access to the other compartments of the MDC.

Concerning the expected service level, reliability, ubiquity and unlimited accessibility as well as ease of comfort regarding use and fast turnaround times vis-à-vis a high throughput of cargo belonged to the most frequent answers. Little surprisingly, the members of the project-internal expert group insisted on low CAPEX and OPEX levels to maximise the likelihood of a successful market uptake. Some respondents also recommended to aspire a competitive price to road transport alternatives while others favoured a distinct pricing policy and marketing strategy. The expected effects regarding traffic include relief of urban congestion

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caused by trucks, increased use of inland waterway transport, optimised last-mile delivery, effective modal shift to environmentally friendly modes of transport like cargo bikes and electric vans for the first and last mile, respectively, and eventually lower emissions.

From the replies of the survey respondents, the most relevant basic parameters and requirements with respect to the above-mentioned basic questions as well as detailed aspects have been collected and consolidated at a later stage. After carefully reviewing all responses, eliminating same or similar replies by clustering them, ranking and, possibly, re-assigning them to further aspects, a renewed list of requirements was compiled.

In a dedicated (virtual) workshop (WS 3), the collected survey replies were concluded as the list of requirements of the MDC concept (see Figure 7-7). More precisely, each function or feature was to fulfil one or several requirements – which again was to be considered for the solution development at a later stage. Hence, the requirements derived from the results of the preceding survey have been presented to the project-internal expert group in order to jointly conclude them as relevant requirements for the subsequent design process. Precisely, the replies to each of the thirteen questions of the preceding survey have been clustered into must-have requirements, nice-to-have requirements and such requirements that are irrelevant to the design of the MDC (see Figure 7-8). Eventually, more than thirty must-have requirements and forty nice-to-have requirements have been listed as input for the design process of the MDC. As expected, most must-have requirements referred to the main purpose of the MDC, its functioning principle, its prospective users, and its traffic-related effects.

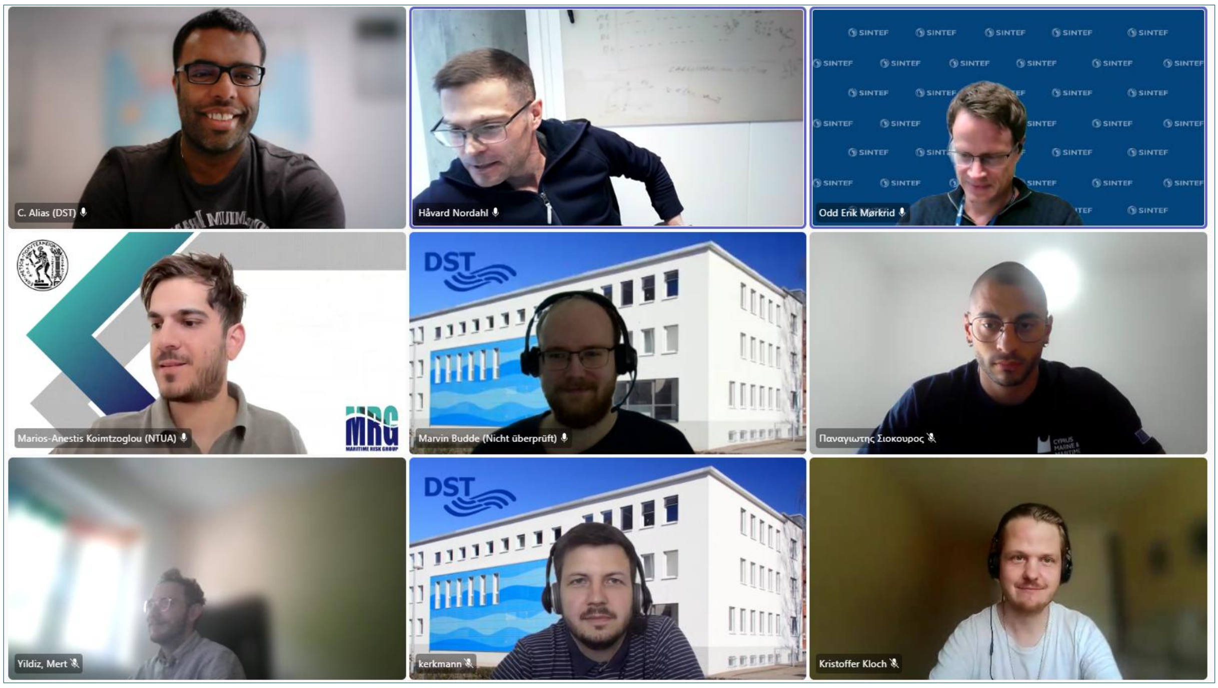

Figure 7-7: Participants of the on-line workshop (WS 3) discussing the relevant requirements of the MDC

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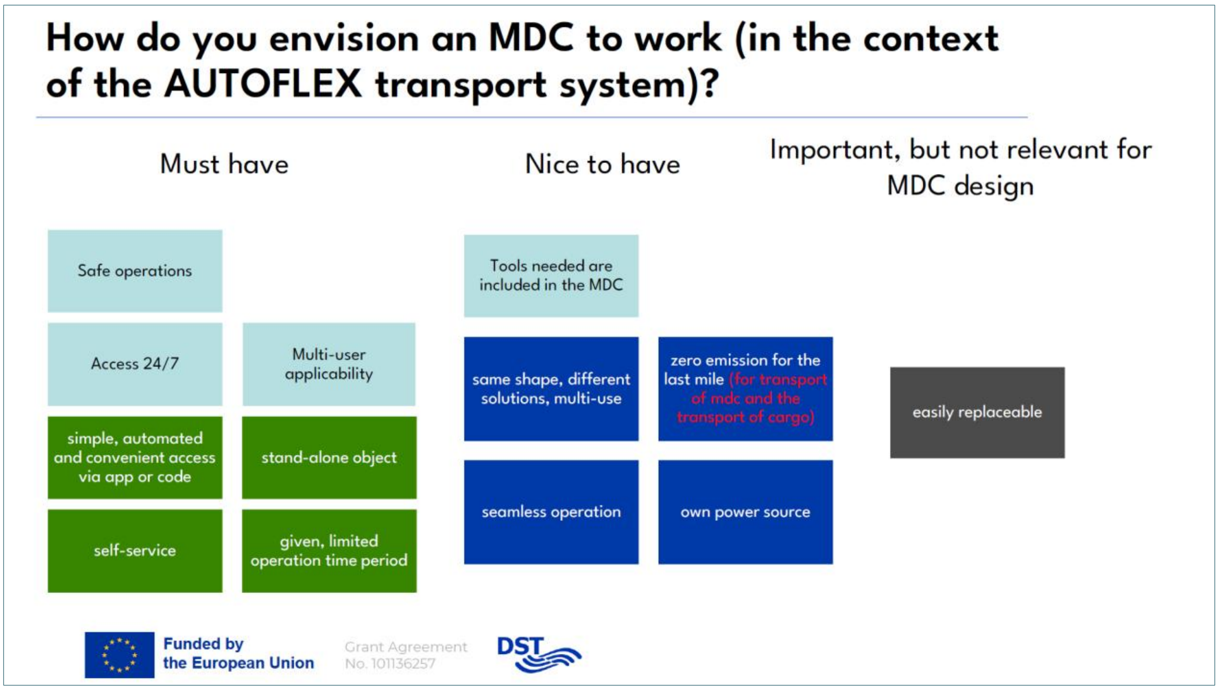

Figure 7-8. Excerpt from the conclusions about the functioning principle of the MDC presented during the on-line workshop (WS 3)

The requirements served as the primary input for the initial design and development steps of the MDC, starting from the ISO container as a base form and separate compartments for individual customers and their respective cargo units on pallets, roll containers, or other transport assets or containers. Moreover, the requirements derived from the responses collected in the survey have been transformed into individual functions or features to be taken into consideration.

By decomposing the concept requirements into functions or features, collecting the requirements of them individually, and developing solution ideas for each of them, a morphological box was set up (see Figure 7-9). For each of the required functions or features, several solution or design options were collected and considered. In total, seven major categories of functions turned out to be decisive while a plethora of criteria was collected (see Figure 7-10).

More precisely, the loading position was open for discussion as the MDC could be loaded via the front doors, via a back entrance using a shutter door at the rear side, via the front door and the rear entrance, via the top of the container, or via roller shutters at the long sides of the container. The loading process could be foreseen in a conventional way or with the help of a rolling tray, plug-in modules, or a mobile robot filling the MDC with the different cargo items. The retrieval position could be located at the rear side with a roller shutter entrance, at both long sides of the container using roller shutters, or at the front door and the rear entrance. Moreover, the spatial arrangement of the MDC containers could be realised in such a way that the manoeuvring space is either in front of the front door or in front of the front and rear entrances or in front of the side entrances. Next, the retrieval method could vary between manual retrieval, using a tray, employing a mobile robot, and using rails to move the cargo (on wheels or trays) around. With respect to the energy management, batteries, solar panels, and a connection to the local power electricity grid are the main options. Finally, the access control could be implemented with the help of a smartphone app, a keypad and a code

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provided via smartphone, a fingerprint scan, a control panel, or a QR code (on paper or on a screen).

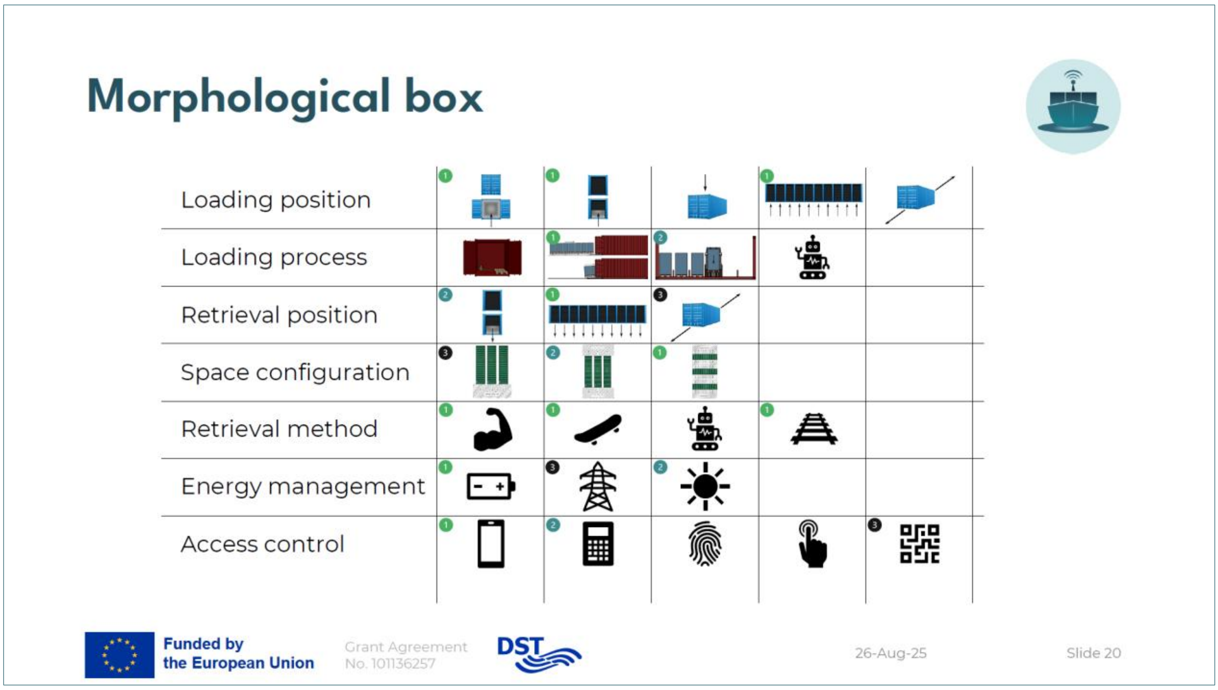

Figure 7-9. Excerpt from the online survey (S 2) on the morphological box of the design options of the MDC

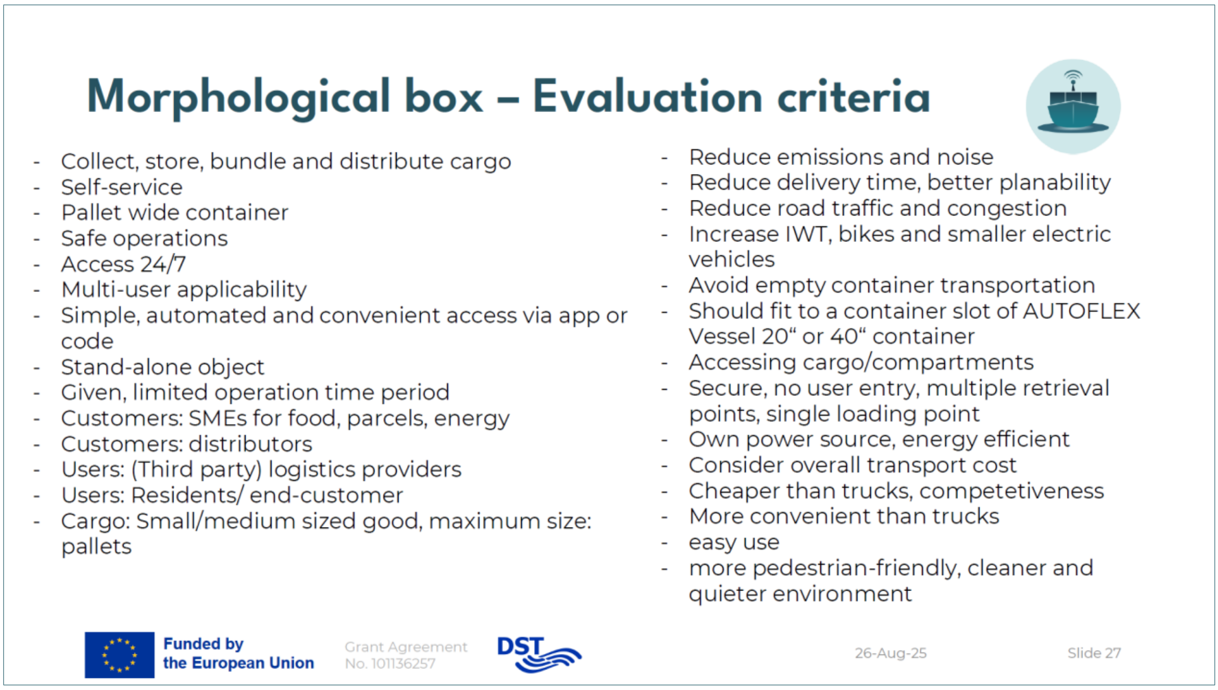

Figure 7-10. Excerpt from the online survey (S 2) on the main requirements serving as evaluation criteria of the MDC concept

With the development process proceeding and the design maturing, the alternative solution ideas per function or feature were presented to the project-internal expert group in a second survey (S 2), indicating their respective benefits and downsides. The survey was conducted as an online poll and yielded the results of a selection voting per function or feature. Each function or feature saw one solution idea (or several ones, in some cases) preferred by the

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expert group which are briefly explained hereafter. The loading position can be located at the front, at the back, or at the long side. One comment in the survey, which had favoured the roller shutter doors at the long side, said: "*This option for faster loading unloading [is] Recommended: Rear Loading or End-to-End (Pass-Through) For standard operations where vehicles back in to load/unload. Especially suitable if the MDC acts like a temporary warehouse. If the MDC is meant for rapid deployment in tight or roadside spaces, side loading may be more optimal*", while another comment added: "*[I] Believe this gives most flexible access both for loading and unloading, and a good compartmentalisation*". The preferred loading process foresees the use of rolling trays – mainly because "*[...] because trays can be moved between containers or set up in advance to make restocking faster*" according to one comment from the survey. The retrieval position for user access is clearly considered to be at the long side of the container while the space configuration is to be designed in such a way that the side doors of two MDCs face one another, leaving sufficient manoeuvring space between them. The explanation for this preferred choice encompasses comments like "*Maybe only doors at one side could be sufficient (that would also save manoeuvring space). Therefore, we might lose flexibility, but save costs and space. Also, I think a crane, that is bale to lift of the container should be able to rotate it*", "*This option in order to be 100% sure that we have visibility and have fully exploited the space*", and "*Mostly due to facilitating that one customer can get access to only one compartment, and that the compartment should be as small as to hold one pallet. Loading through front and back doors would quickly lead to a complicated arrangement for rolling in/out a lot of cargo, or limit access to cargo units (the latter probably implying that one pallet shipments would not be practical)*". The retrieval method saw largely indifference regarding the various options, as manual retrieval, trays, and rails scored the same number of votes for them. With respect to trays, the respondents commented "*It should be as simple as possible, at the same time as it must be practical and easy to use. It should also be easy to install the equipment in a standard container without too high costs*" and "*Because it offers good reliability, quick recovery, and efficient space utilization without the added complexity of other systems*". Batteries are the preferred option for energy management of the MDC. One comment elaborated that "*The MDC should independent. The most feasible solution for that seems to be battery. Solar panels could be an interesting add on (since panels are quite cheap and they offer a regenerative cheap recharge). But since MDC's could be stacked over each other the PV-Modules need to be incorporated in the roof and should be very resilient to possible damage*". Access control is foreseen by means of a smartphone app, potentially combined with a keypad at the MDC and a code to enter. The respondents added explanations like "*My experience is that the app for smartphones, QR codes, and manual codes, for parcel retrieval works very well. Biometric solutions seem unnecessarily complicated here. Since we are addressing commercial users, a key card could also work*" and "*Entering a code into a keypad is practical choice because is simply, economical and easy to use. If paired with additional authentication factors, it can achieve a high level of security*". Figure 7-11 shows an overview of the design choices of the MDC derived from the morphological box. In the following, the conceptual design of the MDC and its development could be completed with the results of the second survey.

In the next *(virtual) workshop* (WS 4), last questions were resolved and decisions made with the help of the project-internal expert group, so that the final selections per function or feature could be completed (see Figure 7-12). Eventually, the morphological box was narrowed down to individual decisions of precise solution ideas, and the design of the MDC concluded. Details of the final MDC concept are presented in section 7.5 .

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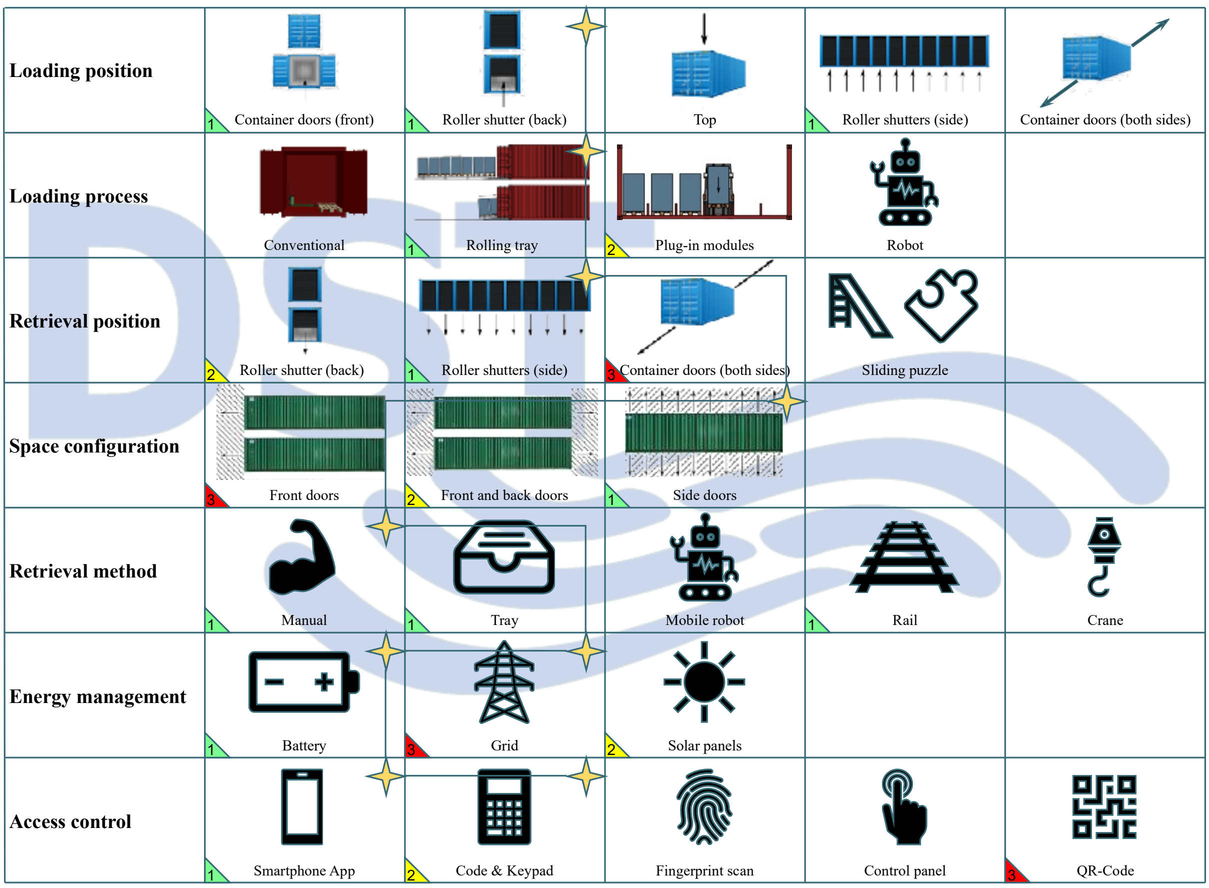

Figure 7-11. Final design choices of the MDC derived from the morphological box

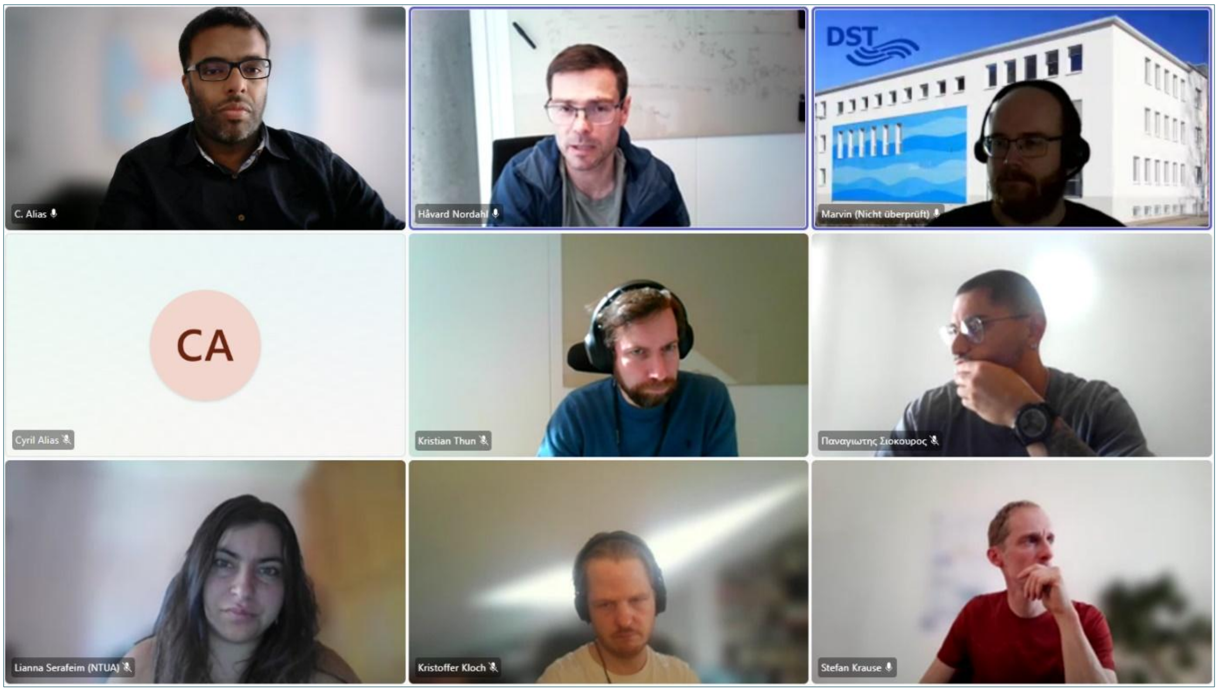

Figure 7-12. Participants of the on-line workshop (WS 4) discussing the final design choices of the MDC

Ultimately, both the project-internal expert group as well as selected external stakeholders were invited to participate in the third and last *survey* (S 3) and discuss and elaborate the concept and its precise design choices in an *on-site workshop* (WS 5) in Hamburg, Germany, in October 2025 (see Figure 7-13 and Figure 7-14).

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The final survey (S 3) to discuss the final MDC concept has been conducted as an online poll and was designed according to the Six Thinking Hats method developed by Edward de Bono (Bono, 1990). The method is a structured way of thinking about and discussing problems, in which the participants consciously adopt six different mental hats, each representing a specific perspective, so that discussions become clearer, more creative, and less contentious. The six different perspectives are represented by one of six different colours of hat, one per perspective. The colours symbolise the respective attitude that one acquires with the corresponding hat. The number of different possibilities is manageable and yet versatile enough.

- The white hat: objectivity and neutrality – calls for information known or needed

  The white hat focuses on information and data. It involves identifying known facts, uncovering what is missing, and clarifying which additional information is required, without adding interpretation or evaluation.

- The red hat: the entirely subjective feeling, the personal opinion – signifies feelings, hunches and intuition

  The red hat represents emotions, intuitions, and spontaneous reactions. It allows individuals to express their feelings, likes and dislikes, and gut instincts openly, without the need for justification or logical explanation.

- The black hat: objectively negative aspects – thinks of risks, difficulties, problems

  The black hat stands for critical judgment and caution. It is used to identify risks, weaknesses, possible errors, and negative consequences, thereby helping to prevent imprudent decisions and highlighting points of concern.

- The yellow hat: objectively positive aspects – explores the positive and probes for value and benefit

  The yellow hat emphasizes benefits and positive aspects. It directs attention to strengths, opportunities, and potential value, exploring why an idea might work and under which conditions it could be successful.

- The green hat: towards new ideas – focuses on creativity, the possibilities, alternatives, and new ideas

  The green hat is associated with creativity and new ideas. It encourages the generation of alternatives, innovative approaches, variations, and modifications, without immediately assessing their feasibility or quality.

- The blue hat: Being a conductor – manages the thinking process overall

  The blue hat governs the thinking process itself. It is concerned with structuring and managing the discussion, defining objectives, determining the sequence of the other hats, and summarizing conclusions and next steps.

When the project-internal expert group and the external stakeholders have been presented the survey and its underlying method, they were asked to remember the respective hat (and related perspective) when replying to each question about the MDC (see Figure 7-13). Moreover, they should also bear in mind their particular role, such as Chief Regulatory Officer in the Industry, Senior Advisor in Shipping, or Administrator with a Policy Maker, when replying to the questions of the final survey.

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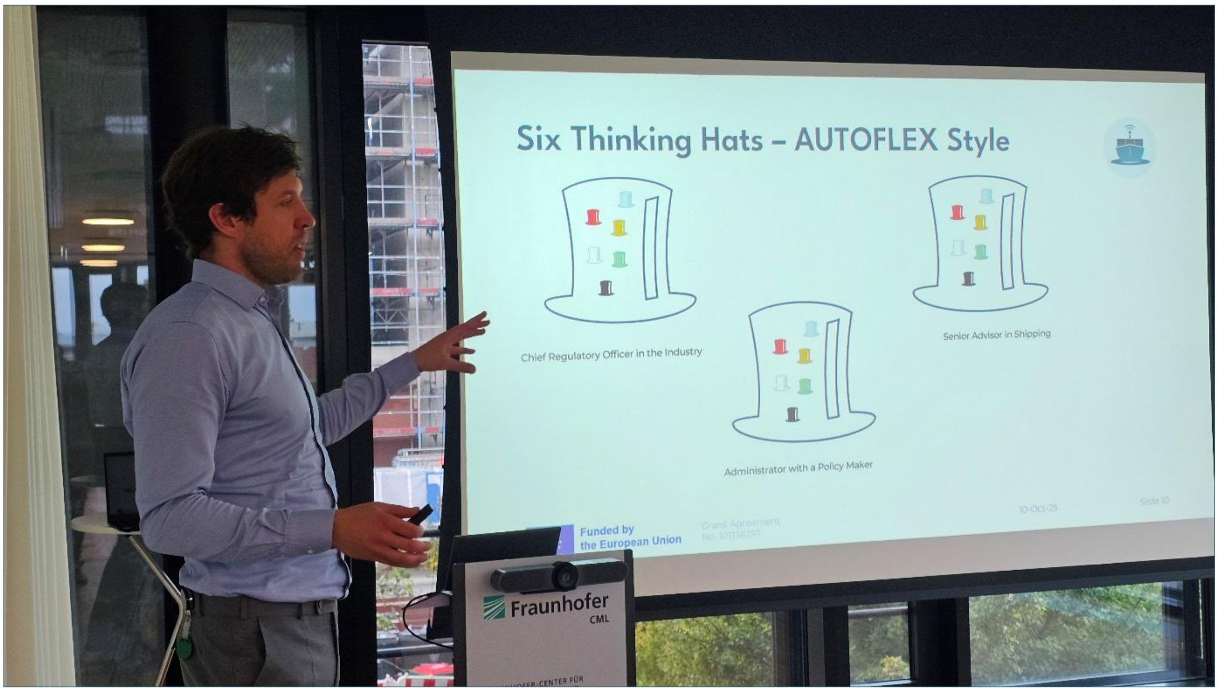

Figure 7-13. Explaining the 'Six Thinking Hats' method underlying the final survey (S 3)

Figure 7-14. Discussing the final concept of the MDC during WS 5, the final on-site workshop in Hamburg, Germany

Accordingly, the six leading questions of the survey were the following ones:

- What do we still need to find out about the applicability of an MDC? (white hat)
- How do you feel about the MDC as a means to tap new intermodal transport market segments? (red hat)
- How can we develop the MDC concept further, possibly to combine it with other aspects? (green hat)
- Why is an MDC a promising idea to tap new intermodal transport market segments? (yellow hat)

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- What systems and processes do we still need for an efficient use of the MDC? (blue hat)
- What are the possible drawbacks, risks, or problems related to the current MDC design? (black hat)

The questions have been answered and the replies discussed during the on-site workshop by its participants. With a total of twenty workshop participants and roughly a third from external stakeholder organisations, the experts represented a broad set of perspectives of the inland waterway transport eco-system. Each of the above-mentioned six leading questions was presented individually to the participants so that answers could be given in ample time – as shown in the example of the 'yellow hat' question (see Figure 7-15 and Figure 7-16).

With respect to the 'white hat' question ("*What do we still need to find out about the applicability of an MDC?*"), the survey respondents identified multiple gaps in understanding MDCs, focusing on practical deployment and feasibility. Uncertainties included optimal city locations, allowable quay dwell times, parameters affecting siting (e. g., domain occupation, power supply), and handling access from and to inland vessels for smaller vehicles or cycles. Questions also arose on quay-side power connectivity (vessel grid vs. quay) and infrastructure manager perspectives. Key needs involved detailed loading/unloading processes on vessels and land (including equipment like pallet lifters, ramps, or rollers), fireproofing of containers, and quantification of operational limits. Responsibility for malfunctions remained unclear. Also, respondents sought clarity on regulating authorities for inner-city cargo sites, ground allocation (e. g., port-style rental), and overall accountability for placement and operations. Gaps covered main customers and goods for cargo consolidation, integration with existing supply chains, customer demand validation via end-user feedback, operational costs (e. g., from cargo breaking), and business operators. Other areas included aspects like security and privacy, (physical/digital) accessibility, and potential applications like boat+cycle logistics for food, waste, or recyclables. Many responses express uncertainty ("I don't know"), underscoring the need for further research.

Regarding the 'red hat' question ("*How do you feel about the MDC as a means to tap new intermodal transport market segments?*"), the replies revealed a mix of optimism, concerns, and uncertainties. Respondents appreciated its potential for flexibility and efficiency but highlight practical and aesthetic hurdles. Many viewed the MDC favourably for enabling waterway use, reducing empty truck traffic, and offering pick-up flexibility for busy customers. Others praised it as an innovative concept for local entrepreneurs, with strong branding potential and proof-of-concept parallels to parcel lockers. Comments like "great idea," "I feel good," and "proper solution" reflect enthusiasm for its market-opening possibilities. Visual appeal was said to be a frequent drawback for inner-city settings, alongside questions on durability in rough port handling, power supply, goods safety, and stay duration. Some worried about added complexity for end customers, variable timelines, and location unpredictability causing stress. Regulatory ease for dangerous goods was noted positively, but urban disruption and format preferences (e. g., trailer/RoRo) raised doubts. A few expressed "I don't know" or suggested clarifications before commitment, balancing intrigue (e. g., truck integration) with unresolved aspects like city impacts. Overall, positivity edged out concerns, contingent on addressing logistics and usability gaps.

Concerning the 'green hat question' ("*How can we develop the MDC concept further, possibly to combine it with other aspects?*"), the survey replies proposed enhancements to make MDCs more versatile, integrating with trucks, bikes, reverse logistics, and tech features. Suggestions included mounting MDCs on trucks or trailers for land mobility, designing as self-driving or

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Lego-style modular units (not fixed containers), and enabling underground placement to save surface space. Others advocated fitting small containers on e-bikes for last-mile delivery or allowing non-static, non-quayside distribution. Ideas featured mini Stow & Charge concepts for phone charging, solar cells on top, reefer (refrigerated) services, e-bike charging stations, phone apps for access control (with PIN panels inside boundaries), and bidirectional cargo use so that customers could both load and retrieve items. A broader integration with a focus on reverse logistics, security emphasis, learning from parcel locker models, niche markets amid urban delivery restrictions, and varied internal designs for different cargo sizes appeared feasible. Battery use was questioned for beyond basic operations, with ongoing crane dependency noted.

As to the 'yellow hat' question (*"Why is an MDC a promising idea to tap new intermodal transport market segments?")*, the respondents highlighted the MDC as a promising idea for intermodal transport due to its flexibility, sustainability, and integration potential. Respondents emphasised reduced CO_2 emissions, fewer trucks in city centres, and greener last-mile delivery, including night-time vessel operations in congested urban areas. It incentivized rethinking logistics to minimize empty truck runs and enable battery-powered small transport like e-bikes. MDCs were expected to offer route and terminal adaptability beyond large systems, support smaller parcels (even for private users), repeated access for local shops, and additional "stations" in supply chains. They scale easily, fill containers faster to cut costs, and extend vessel flexibility while easing load breaks. Key advantages included attracting new clients to inland waterways, building on standards like ISO containers for easy integration, simplifying quayside/port management, and serving as a prototype for future solutions.

Figure 7-15. Question about expected benefits of the MDC (yellow hat)

Figure 7-16. Replies to the question about expected benefits of the MDC (yellow hat)

The 'blue hat' question (*"What systems and processes do we still need for an efficient use of the MDC?")* yielded critical gaps in regulatory, operational, tracking, and logistical systems to enable effective MDC deployment. Key needs included one-stop approvals for inner-city use, permits for hazardous goods in populated areas, liability rules for malfunctions or illegal access, and cleanup responsibilities. Moreover, respondents called for defined processes on placement (accessibility, quick-win rollout order), dwell-time limits (e. g., 72-hour pickup), rental schemes ("take or pay"), and spare capacity offloading. Essential systems were expected to involve real-time tracking of MDCs and users, CCTV for authentication, manual overrides for touchpad failures, and "lost luggage" protocols. Priorities regarding handling and infrastructure were vessel loading/unloading methods, shore-based transshipment (silent LoLo, small cranes), predictable delivery, roller door suitability in snow/ice, cooling systems, and equipment balance to avoid waste.

Concerning the 'black hat' question ("*What are the possible drawbacks, risks, or problems related to the current MDC design?*"), the survey replies highlighted operational, security, aesthetic, and scalability issues with MDCs. Concerns included dependency on LoLo (not RoRo/trailer) systems, potential instability, weather/water-tightness issues (especially in holds or inland waterways), noise conflicts (night quayside vs. day waterside), dirt post-removal, and inconvenient vessel/final-site loading/unloading. Delays from cargo consolidation waiting, last-mile handling costs, and reduced space for larger goods were noted as well. Risks involved sabotage/break-ins during unattended periods, illegal goods access via rollers, unclear insurer interest, and sustainability of quay electrification. Drawbacks encompassed high complexity limiting scalability/reliability, unclear business models, insufficient demand, authorities blocking quay use, customer inconvenience (self-pickup vs. door delivery), unappealing grey urban aesthetics, and specialized needs (e. g., food vs. chemicals). Moreover, the respondents feared that variable fill cut-offs could misalign transport chains.

While the vast majority of replies have been discussed in the workshop, a set of questions remained pending and have been addressed to the respondents in written form in the aftermath of the workshop. Consequently, the design and development process of the MDC has been completed while the final MDC demonstrator, a real-scale mock-up model of the envisioned MDC concept, has been built in the HaFoLa Port Research Lab of DST in Duisburg, Germany for presentation purposes. Figure 7-17 shows the final concept of the Mobile Distribution Centre along with its main functions and features.

7.5 FINAL MDC CONCEPT

The final configuration of the Mobile Distribution Centre is founded on a pallet-wide ISO container module (as can be seen in Figure 7-18), available in twenty- or forty-foot variants, to facilitate seamless transport and transshipment operations onto and from both SFAZ inland vessels (and conventional ones). This modular architecture allows for scalability in deployment, ranging from a single MDC unit to multiple distributed sites, depending on logistical requirements. The inherent dimensional flexibility of the MDC design enables exploitation of diverse economic potentials across distinct market segments and geographic regions. Furthermore, the functional specification of the MDC is deliberately left open-ended to accommodate both collection and distribution operations. Likewise, cargo type specifications remain non-restrictive, thereby permitting integration with a wide spectrum of transport bins, load carriers, and structural configurations.

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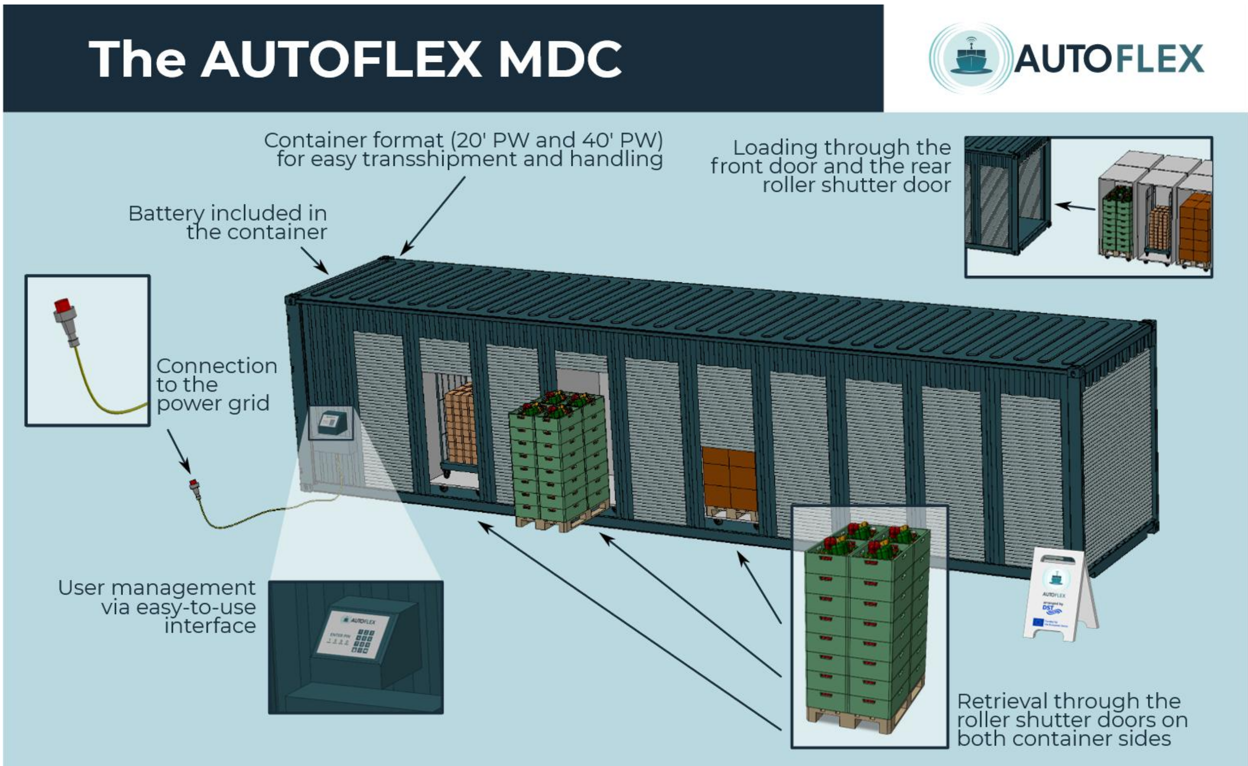

Figure 7-17. Final concept of the Mobile Distribution Centre

It should be noted, however, that the container design constrains permissible cargo dimensions, necessitating that goods be handled on standardised pallets, within roll containers, or comparable modular transport units. The dimensional constraints and operational implications may need to be discussed in view of future application areas and examples. Accordingly, the spatial configuration of multiple MDCs is foreseen in a longitudinal manner, so that the doors can still be accessed by the potential users.

The final concept of the MDC resembles an ordinary ISO container but features additional roller shutter doors on those three sides of the container which do not feature the main door (see Figure 7-18 and Figure 7-19). Thereby, the MDC can be opened and accessed from all four horizontal directions.

Moreover, the inside part of the MDC is subdivided into different units, so-called cargo compartments, for individual storage slots (as shown in Figure 7-20). This can be realised by means of trays or platforms with wheels underneath and fenced units on it or with the help of multiple roll containers, each of which can accommodate the different cargo items like pallets, (yet other) roll containers (like the ones used in the retail business), or mini-containers (like the ones used by cargo bikes), to name a few (see Figure 7-21 and Figure 7-22).

In this way, sufficient flexibility in the loading process, e. g., due to spatial constraints, is ensured. In the standard case, loading takes place using the front door and the roller shutter entrance at the rear end. In exceptional cases, loading the individual storage spaces can even be realised from the lateral side through the roller shutter doors of each cargo compartment. Figure 7-22 shows the loading process from the rear end of the MDC, when the roll containers carrying the individual cargo items are pushed into the MDC. Figure 7-20 and Figure 7-21 show the MDC equipped with the individual cargo compartments and, thus, ready for transport and transshipment.

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The lateral openings are actually designed for the retrieval by the user. A standard forty-foot container features ten openings on each of the two long sides of an MDC container. Retrieval is foreseen as a static picking process from each cargo compartment, e. g., manually with pallet trucks, with forklifts, or using other industrial equipment (see Figure 7-23). However, the introduction of a dynamic picking strategy, possibly using rails or even mobile robots to fetch the requested cargo from its compartment and to eject it at a central pick-up point or a predetermined opening of the MDC, is possible at a subsequent stage.

User management, including identity and access control, is ensured by means of automated locks opening and closing the individual roller shutter door as well as a graphical user interface (GUI) unit at the outer container wall through which the user can gain access to the entitled cargo units. Users shall be enabled to either use their own mobile phone or the GUI screen.

In order to provide the MDC with the required energy, both a connection to the power grid (as proven effective for reefer containers) and a battery unit inside the MDC is foreseen. In the future, the integration of solar panels should also be possible. The energy is required for the access management modules, including the GUI screen as well as roller shutter doors. In future, the energy might also be required for the realisation of a dynamic picking strategy inside the MDC.

Figure 7-18. Resemblance of the final MDC concept with an ordinary ISO container

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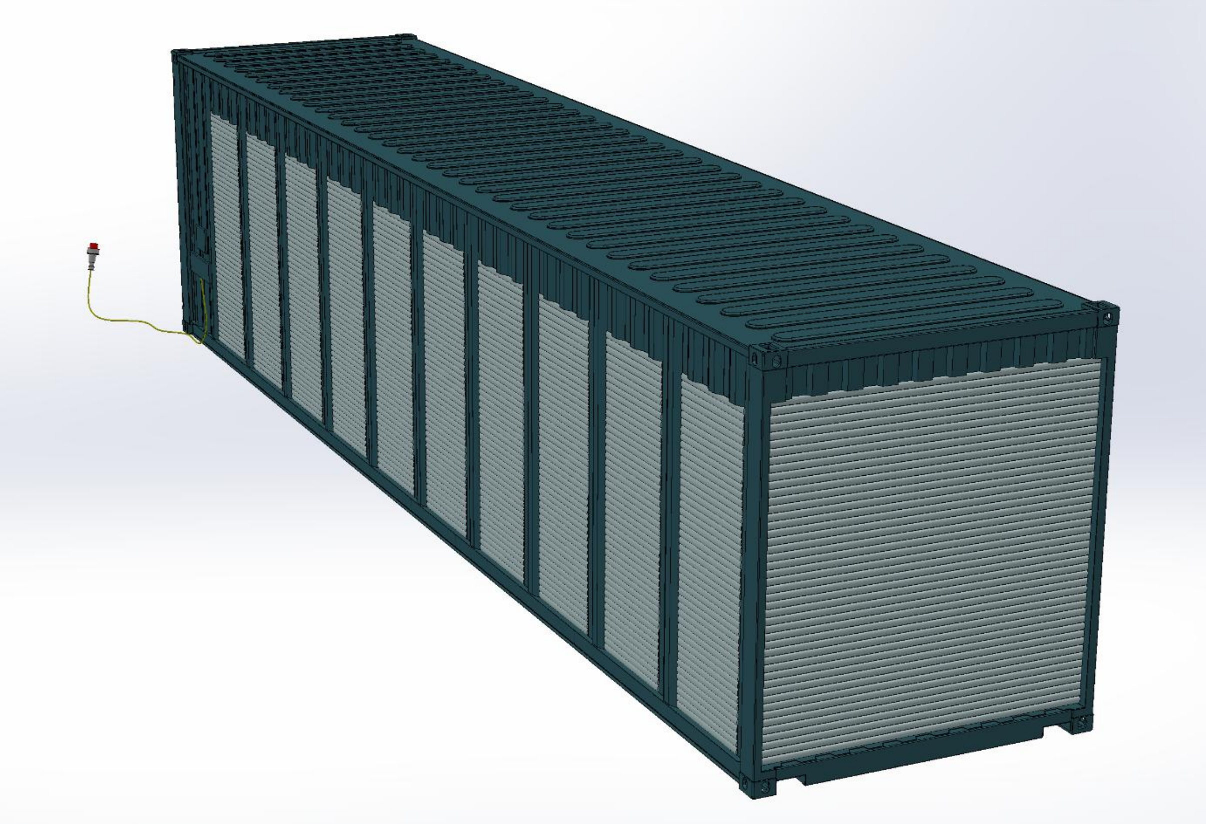

Figure 7-19. Accessibility to the MDC via the front door and roller shutter doors on all three sides

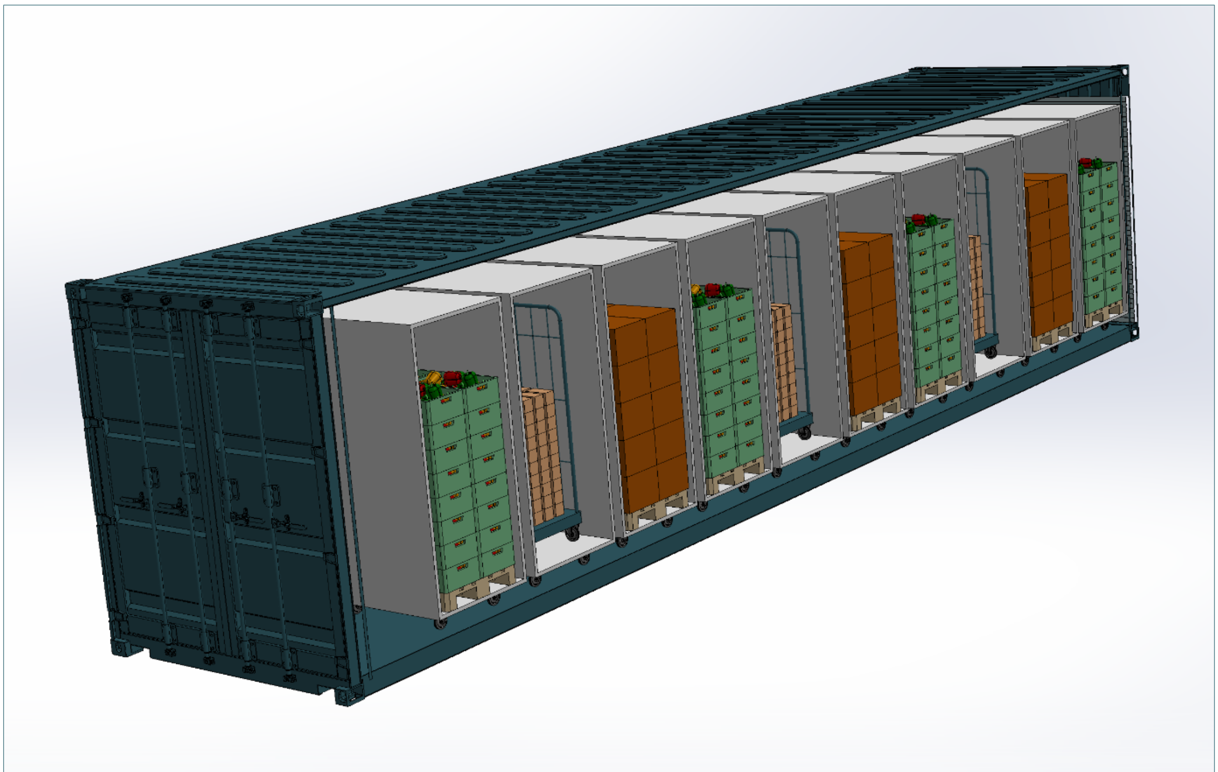

Figure 7-20. Roll containers within MDC form cargo compartments and allow easy retrieval

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Figure 7-21. Roll containers are loaded into the MDC via the rear end

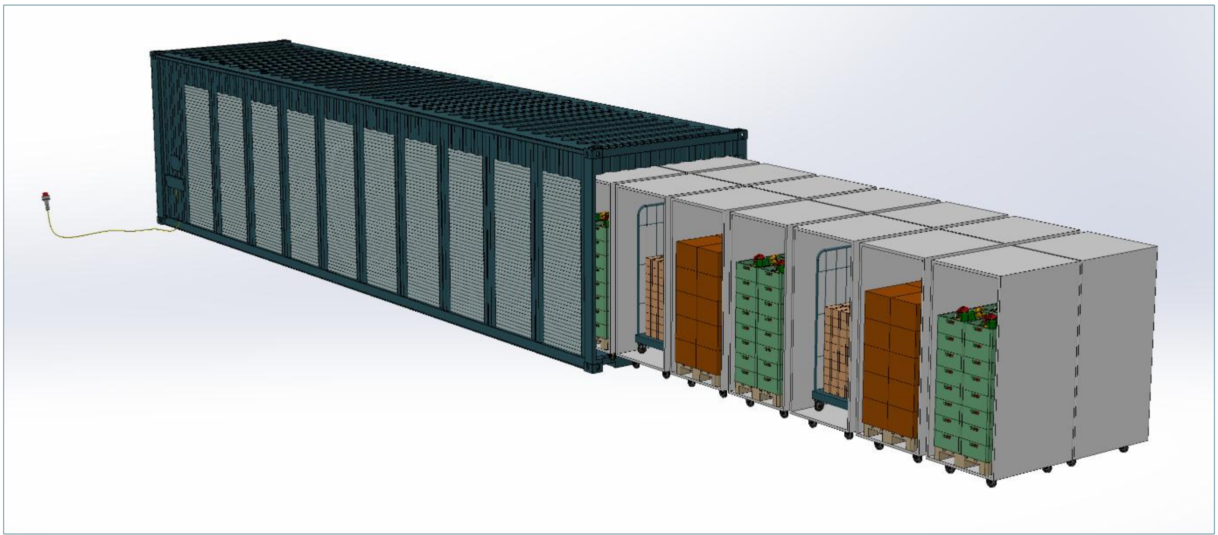

Figure 7-22. Loading the MDC via the front door and the rear end, using roll containers and the roller shutter doors

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Figure 7-23. Roller shutter doors at the long side of the MDC allow manual retrieval from single compartments

7.6 RELATED WORK

The expected benefit of the LVL service concept becomes tangible when compared to other micro-depot and parcel locker solutions with respect to transport performance effects. In Norway, a study conducted by the renowned, Oslo-based Transportøkonomisk institutt (English: Institute of Transport Economics; TØI) along with Posten Norge, the national postal service provider in Norway, has proven a significant reduction of mileage per parcel (Caspersen et al., 2023). Similar studies are available for other European countries as well (SESAM, 2020).

Micro-depots, distribution centres and similar concepts for urban and regional transport services have been the focus of extensive research over a considerable period of time to reduce traffic congestion, pollution, and service inefficiencies. While larger facilities close to the service centre are referred to as urban consolidation centres, smaller facilities close to the delivery point are called micro consolidation centres, city hubs, micro depots, or micro-hubs (Gunes, 2021; SenMVKU, 2025). If a vehicle (e. g., trucks, barges) is used and acts at the storage from which smaller vehicles (e. g., cargo bikes) transport the cargo to their final destinations, the concept is called mobile (micro-)depot or mobile (micro-)hub (Arvidsson & Pazirandeh, 2017).

Janjevic et al. (2013) reviewed existing small-scale consolidation solutions, such as micro-consolidation, micro-depots, or micro-hubs, and assessed how transferable such

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initiatives are between different urban contexts and city logistics systems. They considered micro-consolidation as a promising complement to other city-logistics measures, particularly for enabling cleaner, smaller vehicles on the last leg, but not as a universal solution.

R. van Duin et al. (2018) investigated how key urban freight stakeholders in the Netherlands view policies around Urban Consolidation Centres (UCC), and how these differing views help explain the mixed success of UCC initiatives. Four dominant stakeholder perspectives structure the urban freight policy debate around UCCs, highlighting clear disparities between umbrella industry associations, divergent expectations about the expected activity level of public administrations, and the mismatch between what shippers and LSPs regarding their claimed values and their actual behaviour.

Earlier, Quak and Tavasszy (2011) analysed when and how UCCs can be a viable and sustainable solution for city logistics, emphasising that they only work under specific local and organizational conditions rather than as a universal "one-size-fits-all" measure.

Rosenberg et al. (2021) explored the concept of a shared network of micro-depots with parcel lockers as a sustainable last-mile logistics solution for B2C parcels in cities. According to their findings, shared micro-depot networks with parcel lockers offer a promising, scalable pathway to more sustainable last-mile logistics – despite the complexity and context-dependence of implementation, if existing governance and planning challenges are overcome.

Marujo et al. (2018) evaluated whether using mobile depots combined with cargo tricycles for last-mile delivery in Rio de Janeiro is environmentally, economically, and socially more sustainable than conventional truck-only distribution – and concluded that such mobile depots can significantly enhance the sustainability of urban freight distribution, but only under appropriate spatial, regulatory, and demand conditions. Hence, they recommended cities should treat mobile depots as context-specific tools within a broader sustainable urban logistics strategy rather than as a universal solution.

In the WISTAR project, funded in the Interreg North West Europe programme, a strategy for leveraging IWT to create sustainable, energy-efficient logistics solutions for small rural businesses in France), Germany, and Belgium is outlined. Therein, the market demand for IWT services was analysed, the transport infrastructure evaluated (with a focus on small electric inland vessels, flexible transshipment points mapped (in order to connect rural-urban supply chains), and specific recommendations for policy harmonization, digitalization, and stakeholder collaboration per region provided. Apart from electric inland vessels, reusable plastic crates for cargo delivery, a delivery network based on cargo bikes and electric vans, and supporting tools for spatial planning and cost and performance simulation, a scalable concept for transshipment points belongs to the key elements of the project. The concept foresees simplified hubs , designed to enable flexible, low-cost cargo transfers between transport modes (Delferrière, 2025; Szymiczek et al., 2025).

An assessment of (research) initiatives that are similar to the MDC concept yielded 69 data points in total. Subsequently, these initiatives were analysed based on different attributes. The MDC concept is characterized by its shape, indicating the structure of the storage used to store various cargo types and the vehicle type used for last mile delivery. The shapes were grouped into container, vessel or building, while vehicle types involved were cargo bike, electric delivery vehicle or heavy goods vehicle. As can be seen in Figure 7-24, ten concepts employ containers, six employ vessels, and 34 employ buildings as their shape. The last mile is performed by cargo bikes in 29 instances, with electric delivery vehicles in 46 instances, and

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with heavy-goods vehicles (HGV) in twelve cases. All 69 (research) initiatives, including information about waterway utilisation and their respective start and end times, are listed in Table 7-1.

Only ten out of 69 concepts utilised inland waterway transportation. Out of these ten concepts, six employed vessels and three employed buildings. The last mile was carried out using cargo bikes in four instances, electric delivery vehicles in five instances, and HGVs in three instances. Since it was not always possible to retrieve the information for all initiatives, the numerical data does not align as some cases remain unelaborated.

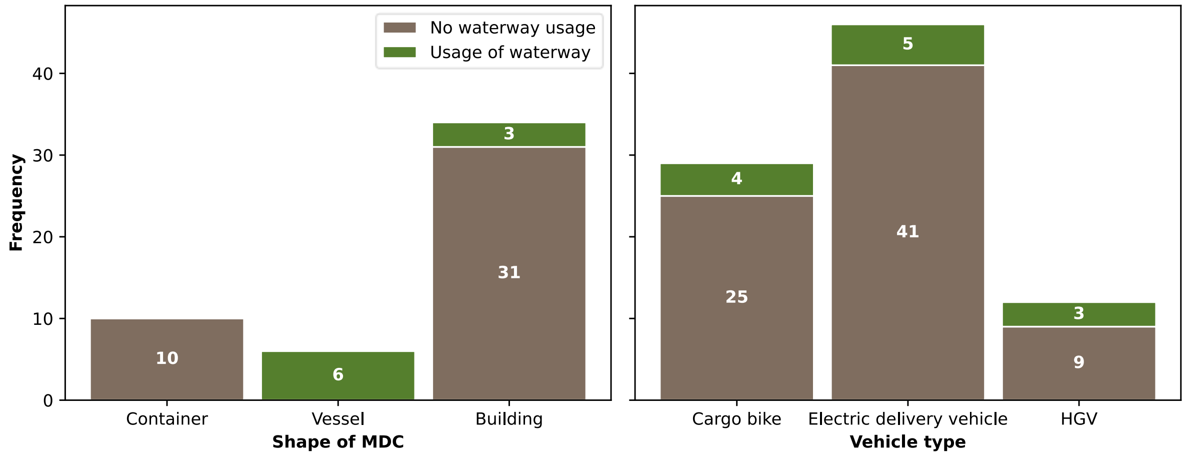

Figure 7-24. Frequency of shape and vehicle type used in related initiatives around micro-depots

Additionally, some concepts utilized multiple shapes for storage or vehicle types for last-mile distribution as described in one case developed in a European research project (Beck et al.) where HGVs and cargo bikes were utilized. The service lifetime is also subject to variation. Certain concepts, like the Hammarby Waterfront Logistic Centre for construction material in Hammarby, Sweden, specifically created for a redevelopment project, are intended for a specific purpose and are only temporarily operational during it (Campbell et al., 2010). Other concepts, on the contrary, are designed for continuous operation.

Private transport companies cooperated in Kassel, Germany, in order to improve their environmentally friendly image. In 1994, an urban consolidation centre was established to consolidate and deliver by a single carrier. The initiative doubled the capacity use of vehicles resulting in reduced vehicle kilometres inside the city by 60 percent. A halt of subsidies by the municipality caused a slow collapse in use due to increased prices (J. H. R. (. van Duin et al., 2010).

Due to a high estimated demand of parcels, an urban consolidation centre inside a car park was established. A second distribution centre would be established outside the city to consolidate cargo. After consolidation, 16-ton vehicles transport the cargo to the car park from where electric vehicles perform the last mile delivery. Although the car park is provided at no cost and an expansion of the service area to the whole city, only one third of the capacity is used.

To improve air quality, reduce congestion, and improve road safety, a project in Perth, Scotland, started in 2010. After a survey, it was determined that small and medium-sized retailers yielded the best results from an urban consolidation centre. After a failed tender process, public subsidies were provided resulting in a trial period over 18 months. Due to a

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lack of interest from the private sector and various other problems, the project was eventually cancelled.

In 2008 an Italian case study of an innovative urban food delivery system was developed. A platform is used to optimize routes providing dynamic routing and scheduling. By utilizing natural gas powered vehicles the project aims to raise vehicles filling rate, reduce environmental impact, reduce the number of commercial vehicles in the city centre and increase the effectiveness of the delivery (Morganti, 2011).

In summary, various concepts with similarities to the MDC concept exist or are being researched. However, solutions specifically designed for IWT, let alone for the introduction of a LVL service, are missing. The conducted research addresses missing IWT solutions and creates new service opportunities.

Table 7-1: Overview of (research) initiatives addressing MDC related concepts

Name (of initiative or initiator)	**Utilizing waterway**	**Start**	**End**
AEGIS	Yes	01.06.20	31.05.23
Amazon	No	2022	Running
Amsterdam, Grachten	Yes	1997	Running
AVATAR	Yes	May 20	Jun. 23
Beer Boat	Yes	1996	Running
Better Bankside waste Consolidation Programme	No	2018	n/a
Binnenstad service	No	Apr. 08	Running
Cargohopper 1	No	01.04.09	n/a
Cargohopper 2	No	2011	2013
Central London Micro Consolidation	No	2017	2019
City2Share	No	01.05.16	30.04.20
cityHUBs	No	08.05.19	Running
CITYLAB	No	01.05.15	30.04.18
CITYPORTO PADOVA	No	n/a	n/a
CIVITAS ARCHIMEDES	No	01.09.08	30.09.12
CIVITAS Mimosa	Yes	2008	2012
CIVITAS PORTIS	No	01.09.16	30.11.20
CIVITAS RENAISSANCE	No	01.09.08	01.09.12
CIVITAS Vivaldi	No	01.02.02	31.01.06
Copeland Park Waste Consolidation	No	01.09.18	Running
DECARBOMILE	Yes	01.09.22	01.08.26
DeConTrans	Yes	Oct. 18	Mar. 22
Deutsche Bahn	No	2020	n/a
DHL	No	2018	Running

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DISCO	Yes	01.05.23	31.10.26
EcoCity (the Parma city logistics project / "Agri-Food & Logistics Centre – CAL")	No	2008	2014
ELCIDIS	No	01.03.98	31.07.02
Esapces Logistics Urban (ELU) - Monoprix	No	2006	Running
First mile	No	2016	Running
Floating Markets	Yes	n/a	Running
Franprix (Paris)	Yes	2012	n/a
GEODIS	No	~2012	n/a
Gnewt Cargo	No	2009	Running
GREEN-LOG	No	01.01.23	30.06.26
Grosvenor Micro Consolidation	No	2017	Running
Hammarby Waterfront Logistic Centre for construction material	No	2001	2004
Heathrow Airport (Heathrow Consolidation Centre and Colnbrook Logistics Centre)	No	2000	n/a
Hermes	No	22.09.23	Running
Home2You	No	1998	n/a
Hub2Move	No	n/a	n/a
HUPMOBILE	No	01.01.19	31.12.21
InnoWaTr (2.0)	Yes	01.04.23	30.06.26
iWald	No	01.12.18	30.11.21
KoMoDo	No	01.01.18	30.06.19
LaMiLo	No	01.05.11	01.06.15
Last mile Leeds	No	n/a	n/a
LEAD	No	01.06.20	31.05.23
MicroPorts	Yes	01.07.22	30.06.24
Mokum Mariteam	Yes	n/a	n/a
MOVE21	No	01.06.21	31.05.25
Multi-carrier Consolidation	No	01.10.14	30.06.15
North London Consolidation	No	01.01.14	Running**
One Hyde Park	No	01.07.06	31.10.10
Paper recycling (Paris)	Yes	n/a	2017
Park_up	No	01.07.17	31.12.19
Polis	Yes	n/a	n/a
Regent Street Delivery Consolidation Scheme, Crown Estate & Clipper Logistics (RSDCS)	No	2008	Running
RegLog	No	1996	n/a

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River'Tri, Lyon	Yes	2016	n/a
Sainsbury's (London)	Yes	Feb. 07	n/a
SAMLIC	No	2004	2006
Scotland, Perth	No	2010	n/a
Seattle neighborhood hub	No	01.01.20	n/a
Seine, Paris	Yes	2012	2014
smartship	Yes	n/a	Running
SMILE	No	01.01.07	31.12.13
Southampton Sustainable Distribution Centre (SDC)	No	2012	Running
Space@Sea	Yes	Nov. 17	Oct. 20
STRAIGHTSOL	No	01.09.11	31.08.14
SUCCESS	No	01.05.15	31.05.18
SURFLOGH	No	01.12.18	30.06.23
The Crown Estate	No	2022	Running
The London Construction Consolidation Centre (LCCC)	Yes	2005	2007
UCC Copenhagen	No	2012	n/a
UCC Kassel	No	1994	n/a
UCC Malaga	No	n/a	n/a
UCC of Leiden	No	1994	2000
UCC of Monaco	No	1989	n/a
UPS	No	2012	Running
Urban Logistic Solutions (ULS)	Yes	n/a	n/a
urbancargo	No	2016	Running
URBANE	No	01.09.22	28.02.26
US coastal service	Yes	2025	n/a
Veolia Waste Consolidation	Yes	2012	n/a
Vert Chez Vous	Yes	2012	n/a
Waterway logistics hubs	Yes	1997	n/a

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8 DISCUSSION, CONCLUSION, AND OUTLOOK

This deliverable has presented the innovations Stow&Charge, Temporary Port Terminal, and Mobile Distribution Centre, which are outcomes of the AUTOFLEX project tasks 3.1, 3.2, and 3.3 (see section 1). The overarching goal that motivated this work was to reduce road traffic and climate gas emissions by shifting cargo to inland waterways, primarily by reactivating underutilised waterways. Section 3 summarized the discussions in [8], where the "5-lever decarbonisation framework" was used as the basis for defining more specific challenges and pathways to solutions to reach the overarching goal. But how do the innovations presented herein address the challenges identified in [8]?

As discussed in section 3.3 the literature review in [8] found that there is significant systemic transport waste due to suboptimal utilization of transport capacities, and that this causes increased emissions and costs. The proposed solution was to develop new consolidation concepts enabling multiple transport customers to share segmented containers at the point of loading and unloading. The solution proposed by the AUTOFLEX project, the MDC, was presented in chapter 7 . Inspired by parcel lockers, the MDC is a redesigned container for distribution of part loads through compartments with exclusive access for the customer. Being designed as a container, the MDC can be transported and handled in any transport network supporting containers. It is also self-contained in the sense that it does not require resources or modifications at the areas where it is placed, it just needs sufficient space.

To discuss how the MDC might impact road traffic, we will direct our eyes to Norway where the Institute of Transport Economics (TØI) has done a study on the environmental impact of using parcel lockers for last mile distribution from online shipping [91]. The study was based on a pilot project where Posten Norge (the Norwegian postal service) placed parcel distribution lockers at selected locations within the Oslo, Bærum, Asker and Drammen municipalities, which have just above 1 million inhabitants combined. The findings were that with strategic planning of parcel locker placements, the average driving distance per parcel is dramatically reduced. As seen by the results, this is especially true in densely populated areas; in Oslo, the Norwegian capital and most densely populated city of Norway, the average driving distance per package for home delivery was 2.5 km, it was 1.8 km for distribution via shops/kiosks, and for parcel lockers it was reduced to 0.87 km. For the other municipalities the results for average driving distance per parcel were 2.5 km for home delivery, 2.83 km for distribution via shops/kiosk, and 1.37 km for parcel lockers. Furthermore, the research showed that just one quarter of the consumers travel by car to pick up a package from a package locker, and out of these, only 34 percent had the package retrieval as the sole purpose for the trip.

From the first parcel locker in Norway was launched by Posten Norge in 2020, the market for such solutions has grown tremendously. And in 2024, Posten Norge had 6000 parcel lockers in 2000 different locations; in Oslo, 59 percent of the population had less than 500 m. from their door to the nearest Posten Norge package locker [92]. Other distributers have also entered into this market, with PostNord at approximately 4000 parcel lockers [93]. Hence, it appears that parcel lockers are replacing significant shares of home delivery and larger "postal office" parcel retrieval points. Considering the findings of the study in [91], parcel lockers have clearly had a positive impact by reducing traffic load and kilometres driven per package.

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Moving back to the MDC, the success of the parcel lockers shows that there is a significant potential for reducing road traffic by introducing cargo consolidation and distribution through strategically placed self-service units. The MDC is the same basic concept as the parcel locker, but at a larger scale. Its impact on transport efficiency, i.e., reduction of road traffic, could hence be expected to be in a similar range as for parcel lockers. If you also consider that the results in [91] is from a fully road-based supply chain, and that the MDC can be transported by the AUTOFLEX vessel to, or close to, the distribution point, one may expect an even greater impact on road traffic from MDCs combined with the AUTOFLEX transport system. Noting the comment in [91] on the importance of strategic planning of the placement of parcel lockers, the upcoming work in AUTOFLEX on designing the transport network will be important in this regard. Though significant progress on identifying strategic locations has already been made in the research related to the TPT, where transport customer clusters (i.e., areas of high customer density) have been identified.

Economics of scale has driven container ship sizes into mega ships, which in turn has led to cargo centralisation around mega ports, marginalisation of SMPs, and unfortunately, to a modal shift towards road transport [8]. The proposed solution in section 3.1 , based on [8], was to reintegrate SMPs through innovative terminal concepts that offer scalable and adaptable solutions that can revitalise SMPs, especially along underutilised inland corridors. The AUTOFLEX solution to this problem is the TPT presented in chapter 5 .

The TPT addresses the challenges that the SMPs face by being a modular solution that can be adapted to existing infrastructure to open new transhipment points in underutilised inland corridors, thereby offering reintegration opportunities. The entry point investment is low as it is possible to start with little equipment, it is possible to grow by adding modules, and it is possible to relocate equipment from one TPT to another. This provides flexibility to adapt to changing demand and in choosing areas for opening new transport services. The importance of this flexibility is that it may reduce investment risk and improve the competitiveness of SMPs.

While the TPT was conceived as a solution for revitalising SMPs by offering expansion opportunities into underutilized waterways, it might also be a significant contribution to the success of the MDC. The TPT will make it possible to open small terminals in areas with high transport demand, either due to high industry or population density. As strategic placement of MDCs is a key to their success, the TPT, intended to be placed within customer clusters, might be the perfect locations for MDCs. In return, it might also have a positive effect on the success of establishing a TPT as it would open for both FCL and LCL customers to use the transhipment service provided by the TPT.

With the TPT and MDC, the AUTOFLEX project has addressed two of the identified challenges discussed in section 3 . The third and final challenge discussed therein, was the need for ports to transition from a single to a dual role as transhipment and renewable energy hubs. This was considered a determining factor for decarbonising supply chains as vessels and vehicles will need access to efficient supply of green energy. However, it was found that SMPs are trailing behind in the transition to renewable energy, which is a challenge for regional economic equity, and a major challenge for revitalising European IWT. The solution proposed in [8] was to develop modular and scalable concepts that combine energy production, storage and delivery, with cargo handling. The AUTOFLEX project solution to this, called the Stow&Charge (or SCH), was presented in chapter 6 .

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The SCH is a scalable solution based on modules for energy production, storage, and distribution. These modules can be combined to create a range of SCH variants, from small and low capacity to large high capacity SCHs. The modularity provides an entry point for SMPs where they can start their zero-emission energy capacity small with the flexibility to grow and adapt as energy demand changes. This addresses the challenges related to SMPs being able to keep up with the mega ports, due to a lack of financial muscles, as required investments to get started is lowered.

In the AUTOFLEX project the energy carrier was chosen to be a ZESpack battery container. This choice offers both a solution for energy storage, and for efficient distribution. Energy storage in battery containers has the advantage of making it possible to move, and hence distribute, the energy by standard terminal equipment. In fact, replacing the ZESpack is essentially the same operation as loading and offloading cargo containers from the vessel. Possibly with some extra time during handling due to a somewhat elevated financial consequence of damaging the ZESpack compared to the average container.

Energy production at SCHs is based on solar panels and windmills, but the SCH could also draw energy from the grid. And in case of surplus production, energy could be delivered to the grid. The preferred option for energy production depends on the terminal area and the available space, as well as the energy demand. While solar panels may exploit the surfaces of building roofs, their production capacity is relatively low. This means that for high production demand, windmills or a grid connection might be needed. Furthermore, the SCH should be placed at a central area in terms of the transport network and vessel range. In summary, restrictions on what makes a location eligible for the SCH concept are; availability of space for production and charging equipment as well as for storage of ZESpacks, vicinity to grid, vessel range and feasibility of covering the desired network from the location.

In section 3 SMPs were identified as playing an important role in overcoming the barriers to shifting cargo flows from road to inland waterways. This is because their expansion to underutilised waterways would provide access to customers of transport services. Today, many of these customers relies heavily on truck transport as there are no waterborne options available. The solutions proposed by the AUTOFLEX project, presented herein, all have a common property; they are flexible and target the forementioned transport customers. The flexibility is achieved through modular concepts where different options for fulfilling specified functions enable adaptation to different applicational areas, through low entry point requirements, through the possibility to relocate the assets, and through the property that they can be scaled up as demand increases. This might provide SMPs with the means to increase their competitiveness as investment risk and dependence on others is reduced, and because they will be provided with the ability to adapt to a changing market. This, in turn, could expand waterway transport services from SMPs into currently underutilised waterways, providing sustainable transport options to the customers.

This deliverable concludes the first phase of the AUTOFLEX work package 3, where we have shown what is technically possible in terms of achieving a shift of freight flows from roads to inland waterways. However, technical feasibility does not guarantee commercial attractiveness. This is why the final year of the AUTOFLEX project will shift focus from technical feasibility to commercial attractiveness. This will be done by combining the innovations presented herein with the AUTOFLEX vessel [1], to form the basis for developing the AUTOFLEX transport system. This will be followed by a study on the potential impact of operationalising the AUTOFLEX transport system, and a study on enabling business models. It is possible that operationalising the AUTOFLEX transport system might require policy

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actions to overcome some obstacles. This is why an analysis of potentially needed actions and support by authorities is also planned for the final year of the AUTOFLEX project, which will conclude with recommendations for changes that facilities the realisation of the AUTOFLEX concepts.

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