City freight distribution with highly automated vessels – Economic assessment and scenario development for urban IWT market uptake

Transport and energy use cases for Hamburg and Ghent

Work package 4 final Report, within the framework of the Interreg NSR project AVATAR work package 4, activity 4

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Table of contents

List of abbreviations

CAPEX	Capital expenditures
CEP	Courier, Express and Parcel
CO2	Carbon dioxide
DHL	Deutsche Post - DHL
DECARBOMILE	Decarbonize the last mile logistics
EPAL	European Pallet Association
EVW	E. VAN WINGEN
HoReCa	Hotels, Restaurants, Cafés
H2 ICE CHP	Hydrogen combustion engine for combined heat and power
ICE CHP	Internal combustion engine for combined heat and power
IWT	Inland waterway transport
IWW	Inland waterways
KLU	Kühne Logistics University
km	Kilometres
kWh	Kilowatt-hour
kWhe	Kilowatt hour electric
LIDAR	Light Detection and Ranging
LIHH	Logistics Initiative Hamburg
MWhe	Megawatt-hour electric
MWh th	Megawatt-hour thermal
NSR	North Sea Region
OHB	Opleidingscentrum voor Hout en Bouw
OPEX	Operating expenditures
POM	POM Oost-Vlaanderen
PV	Photovoltaic
SDGs	Sustainable Development Goals
SME	Small and medium-sized enterprise
SUMPs	Sustainable Urban Mobility Plans

TLR	Technology Readiness Level
TUHH	Technical University of Hamburg
UCC	Urban consolidation centre
WaCaBa	Water Cargo Barge

1. Introduction, objective and approach

Introduction

The massive under-exploitation of inland waterways (IWW) in the North Sea Region (NSR), especially in and around urban environments, provides opportunities for technological innovations. The AVATAR project aims to deploy zero-emission automated vessels that can do regular trips between the urban consolidation centers outside of a city and inner city hubs, focusing on the distribution of palletized goods and waste return.

The AVATAR project aims to tackle challenges of city freight distribution by developing, testing and assessing adequate technologies and business models for urban autonomous zero-emission Inland waterway transport (IWT) solutions. Through this, the project unlocks the economic potential of urban vessels and corresponding waterways, increases available solutions for full-cycle automation and sets up a sustainable supply chain model for urban goods distribution and waste return.

Objectives

This paper focuses on aspects of the economic feasibility of city freight distribution using inland waterways. In order to identify, set up and calculate economic viability and business cases within the project framework of AVATAR, it is necessary to carry out a market review on city freight distribution cases using inland waterways. The report is a summary of the various activities in work package 4, for some of which there are sometimes more detailed versions published in separate documents. Wherever applicable, direct links to such documents have been included for further reading.

Approach

As cities continue to expand and urbanization intensifies, the challenges associated with urban freight distribution become more pronounced than ever. The efficient movement of goods within densely populated areas is crucial for sustaining economic growth, reducing traffic congestion, and minimizing environmental impact. In this context, the adoption of innovative transportation solutions becomes imperative, with urban inland waterway transport emerging as a promising avenue.

This report focusses on the economic assessment and scenario development for city freight distribution with highly automated vessels operating in urban inland waterways. By exploring the potential market uptake of this transport mode, we aim to shed light on the associated opportunities, challenges, and the economic implications for stakeholders.

In recent years, there has been a growing interest in leveraging inland waterways as a viable alternative for urban freight transportation. The utilization of highly automated vessels holds significant potential for optimizing supply chains, improving last-mile connectivity, and reducing carbon emissions. Furthermore, inland waterway transport offers the advantage of utilizing existing water infrastructure, often underutilized or overlooked, providing a sustainable and cost-effective option for city freight distribution.

The economic assessment conducted within this report takes into account various factors, including the investment required for vessel automation, infrastructure development, operational costs, and potential cost savings compared to conventional road-based freight transportation by diesel trucks. By examining the financial viability of adopting highly automated vessels for urban inland waterway transport, we aim to identify key drivers and barriers that may influence market uptake.

Furthermore, the development of scenarios plays a crucial role in the assessment of possible future development of this transportation mode. By considering different scenarios, such as changes in regulations, technological advancements, and shifting consumer demands, we can gain insights into the range of possibilities and better inform decision-making processes.

The findings of this report will serve as a valuable resource for policymakers, urban planners, logistics providers, and other stakeholders involved in urban freight distribution. By understanding the economic implications and potential market uptake of highly automated vessels in urban inland waterways, decision-makers can make informed choices and develop strategies that align with sustainability objectives, enhance efficiency, and create economic benefits for cities.

In conclusion, the exploration of city freight distribution with highly automated vessels in urban inland waterways represents an exciting frontier in the realm of urban logistics. Through comprehensive economic assessment and scenario development, this report aims to uncover the opportunities and challenges associated with this transport mode, paving the way for sustainable, efficient, and economically viable urban freight distribution systems of the future. The report is a summary of the various activities in work package 4, for some of which there are sometimes more detailed versions published in separate documents.

Area of investigation

The study area in this report is limited to the two cities of Ghent and Hamburg. Both cities are characterized by many waterways in the urban area and therefore offer ideal conditions to further develop and promote urban waterborne transport. Another contributing factor is the involvement of the project partners in the AVATAR project: POM Oost-Vlaanderen, E. VAN WINGEN (EVW), and Opleidingscentrum voor Hout en Bouw (OHB). These partners are located in Ghent and are responsible for project management, propulsion development, and vessel construction within the project. The project partner from Hamburg: Logistics Initiative Hamburg (LIHH) will not conduct a real test environment for piloting a vessel, as done in Ghent. However, the LIHH possesses experience in the development and theoretical implementation of logistics-related use cases, working closely with network partners that have a strong focus on the logistics sector.

2. Market review on city freight distribution using inland waterways

This chapter is a summary of a more comprehensive report already published as part of the AVATAR project.

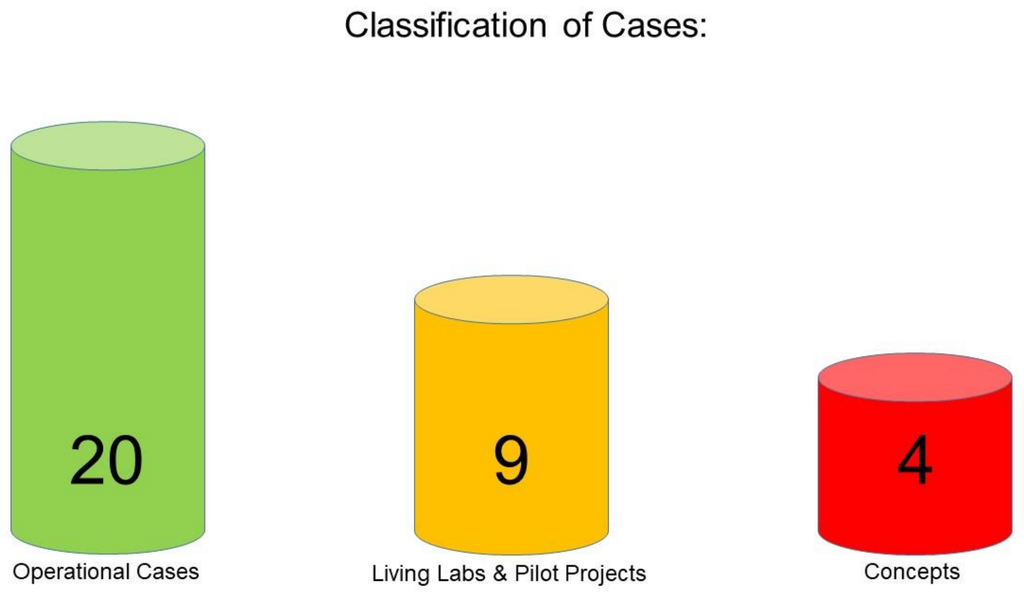
This report, entitled "Market review on city freight distribution using inland waterways", is freely available on the project website.

Numerous use cases exist in city freight distribution via IWT.

This market review summarizes a variety of identified use cases for water-bound city freight distribution. The authors were able to identify a total of 58 use cases. For 33 of which, sufficient information was available and have been presented in use case profiles throughout the chapters 2 to 6 of the published paper. 25 further cases were identified with insufficient publicly available information, resulting in them being listed as further cases under chapter 7. In the following paragraphs, only the 33 use cases for which detailed profiles could be developed are considered.

City freight distribution via IWT can be economically viable in operational terms.

The paper shows that under certain circumstances, economic viability of water-bound city freight distribution can already be achieved today, proven by a total of 20 identified use cases that are running on an operational level.

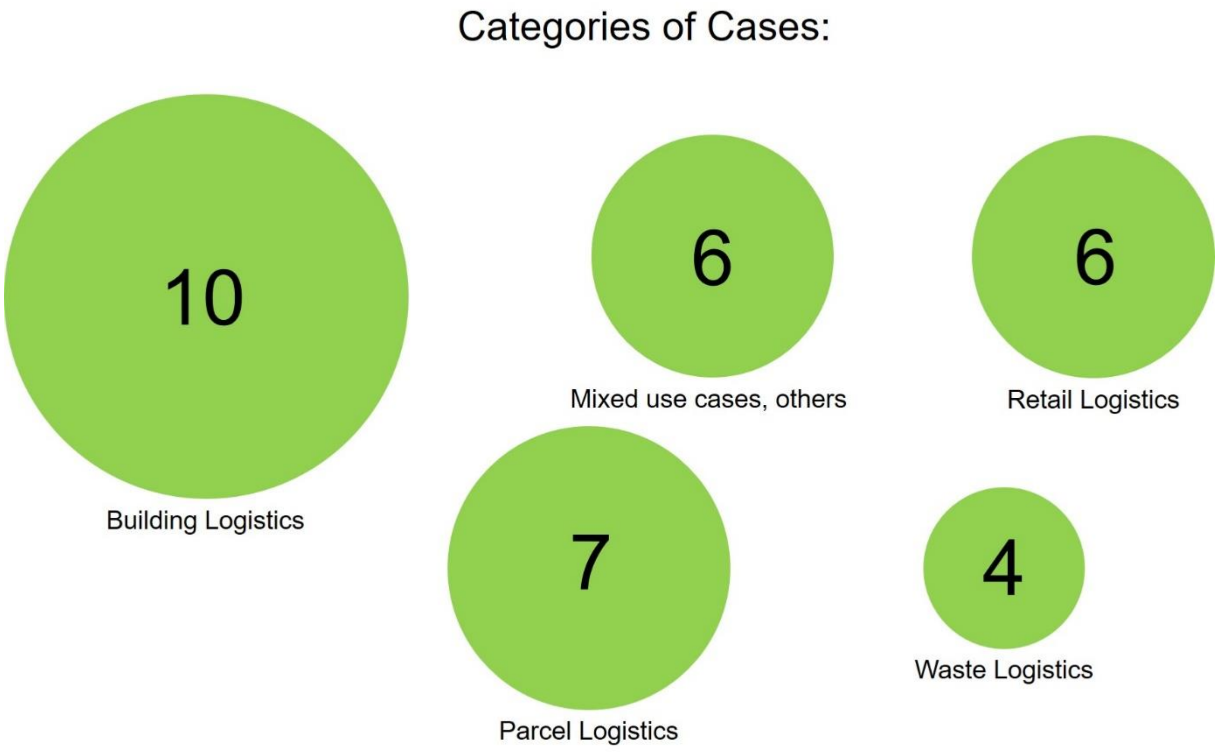


Furthermore, nine use cases were identified and portrayed in the report, that are currently on a pilot or living lab level. Four use cases were identified currently representing concepts.

There are characteristic transport segments that seem to be most suitable for city freight distribution via IWT.

All identified use cases covered the transport of freight/goods, either in the segment of building logistics, parcel logistics, retail logistics or the transport of waste. Building logistics being the most common category (ten cases), followed by parcel logistics, including CEP services (seven cases), retail logistics (six cases) and waste return (four cases).

Mixed use cases (six cases) that were identified usually cover several of the aforementioned transport categories.



France, Belgium and the Netherlands are pioneers in the use of inner-city canals and waterways for urban freight distribution.

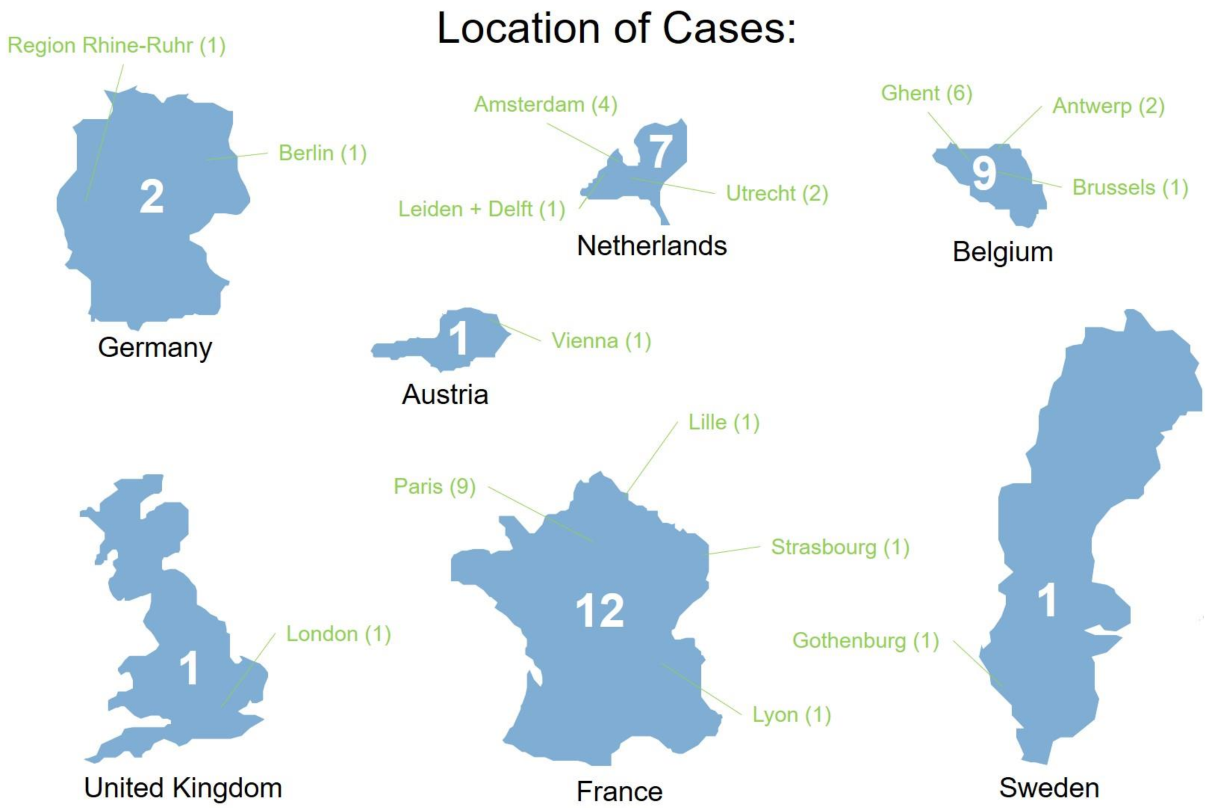
When it comes to the geographical distribution of identified use cases, France (twelve cases), Belgium (nine cases) and the Netherlands (seven cases) are leading by example when it comes to the utilization of IWT for city freight distribution, as of today.

Further cases have been identified in Germany (two cases) as well as Austria, Sweden and the United Kingdom (one case each).

In terms of identified use cases by cities and regions, Paris (France) is the leading city with a total of nine identified cases. In terms of the maturity of use-cases, Paris also leads by example with seven out of those nine use cases being operational as of today. The two other cases are currently in pilot / living lab status.

The second most active city identified in this paper is Ghent (Belgium), representing a total of six use cases. With two of them being operational, three being in pilot status and one being in a concept phase, city freight distribution via IWT is less operationally implemented yet compared to Paris, but Ghent is quite active with their three current pilots. However, the extent to which a direct comparison of a metropolis like Paris with a city of the size of Ghent is admissible would have to be critically questioned here anyway.

Thirdly, Amsterdam (Netherlands) also shows above-average activity in the area of water-bound city freight distribution with a total of four cases, of which three are operational and one being in the concept phase.



Altogether, this shows that water-bound city freight distribution solutions can in general be implemented and achieved in a large variety of circumstances, both in large metropolises like Paris as well as in urban areas and cities with less than 300,000 inhabitants, such as Ghent.

Based on the key findings of this paper, the AVATAR project will now look deeper into the structural success factors for those cases identified in this study but also into factors that hinder or prevent the implementation of such solutions, including infrastructural, economic as well as regulative and policy-related factors.

Furthermore, the core aim of the AVATAR project will be to analyze and elaborate strategies on how the automation of small inland vessels can foster the utilization of urban inland waterways and canals and create a market-uptake of innovative city freight distribution solutions via IWT.

3. SWOT/PESTEL analysis and guideline

The content of this chapter is subject to a separate project deliverable that has been published under the title “Guide for successful implementation of (highly) autonomous zero-emission vessels for inland waterways”. This deliverable is not public available.

The guideline helps cities to determine whether it will be useful to engage in inland waterways distribution with (highly) autonomous zero-emission vessels. Moreover, 10 measures will be described that will be necessary and or useful to possess by cities before introducing inland waterways distribution. Some of these measures will be absolutely mandatory to possess (necessary conditions) whilst others may be only useful and thus not mandatory (supporting or soft conditions).

This document is also useful for private companies who are considering to invest in vessels for city freight distribution.

3.1 Approach

The guide is focused on a SWOT & PESTEL analysis. Based on these two analyses, a top 10 measures is identified for cities that will contribute to successful implementation of inland waterways distribution with (highly) autonomous zero-emission vessels. The top 10 measures guide and strengthen the city’s ability to accomplish inland waterways distribution with autonomous zero-emission vessels. In the different analyses, the Sustainable Development Goals (SDG’s) of the United Nations are taken into account.

3.1.1 SWOT analysis

A SWOT analysis[1] is used as a tool for evaluation of the strategic position of a city or organization. It is intended to specify the objectives of the business venture or project and identifies the internal and external factors that are favorable and unfavorable to achieving those objectives.

The business or project is defined here as using (highly) autonomous zero-emission vessels for city freight distribution. The objective of the project of a city is to lower CO2-emissions by shifting traffic flows from road transport to inland waterways.

SWOT assumes that strengths and weaknesses are frequently internally-related, while opportunities and threats commonly focus are due to the external environment. The name is an acronym for the four parameters the technique examines:

- **Strengths**: characteristics of the business or project that provides an advantage over others.
- **Weaknesses:** characteristics of the business that place the business or project at a disadvantage relative to others.
- **Opportunities:** elements in the environment that the business or project could exploit to its advantage.
- **Threats**: elements in the environment that could cause trouble for the business.

[1] https://www.business.qld.gov.au/starting-business/planning/market-customer-research/swot-analysis/uses

3.1.2 PESTEL analysis

PESTEL analysis[2] (political, economic, social-cultural, technological, environmental & legal) is a strategic tool for understanding market growth or decline, business position, potential and direction for operations.

The PESTEL analysis includes 6 factors:

- **Political factors** relate to how the government intervenes in the economy. Specifically, political factors have areas including tax policy, labour law, environmental law, trade restrictions, tariffs, and political stability. Political factors may also include goods and services which the government aims to provide or be provided (merit goods) and those that the government does not want to be provided (demerit goods or merit bads). Furthermore, governments have a high impact on health, education and infrastructure of a nation.

- **Economic factors** include economic growth, exchange rates, inflation rate, and interest rates. These factors greatly affect how businesses operate and make decisions. For example, interest rates affect a firm's cost of capital and therefore to what extent a business grows and expands. Exchange rates can affect the costs of exporting goods and the supply and price of imported goods in an economy.

- **Social factors** include the cultural aspects and health consciousness, population growth rate, age distribution, career attitudes and emphasis on safety. High trends in social factors affect the demand for a company's products and how that company operates. For example, the ageing population may imply a smaller and less-willing workforce (thus increasing the cost of labour). Furthermore, companies may change various management strategies to adapt to social trends caused from this (such as recruiting older workers).

- **Technological factors** include technological aspects like R&D activity, automation, technology incentives and the rate of technological change. These can determine barriers to entry, minimum efficient production level and influence the outsourcing decisions. Furthermore, technological shifts would affect costs, quality, and lead to innovation.

- **Environmental factors** include ecological and environmental aspects such as weather, climate, and climate change, which may especially affect industries such as tourism, farming, and insurance. Furthermore, growing awareness of the potential impacts of climate change is affecting how companies operate and the products they offer, both creating new markets and diminishing or destroying existing ones.

- **Legal factors** include legislation about anti-discrimination, consumers, antitrust issues, industrial relations, and health and safety . These factors can affect how a company operates, its costs, and the demand for its products.

[2] https://blog.oxfordcollegeofmarketing.com/2016/06/30/pestel-analysis/

3.1.3 TOP 10 measures

Based on the input of the SWOT & PESTEL analysis, a top 10 measures can be identified that will contribute successful implementation. The 10 measures can be ranked. This provides an overview of which measures are an absolute must have (hard measures) and which are good to have (soft measures).

3.1.4 Sustainable Development Goals (SDG's)

The AVATAR energy use case of combining energy flows like heat, electricity and mobility is highly sustainable and translates the principles of economic circularity. The (highly) zero-emission autonomous vessels contribute to the following SDG's of the United Nations[3]:

SDG 3 Good Health -> Sustainable transport
Transportation using (highly) urban autonomous zero-emission vessels via inland waterways improves quality of life. Not only is the air we breathe healthier, it also creates less noise and stress. Local energy systems linked with mobility based on 100% Renewable Energy Systems (RES) ensures the independence of companies from arising risks from oil crises and the operation of nuclear power stations.

SDG 7 Affordable clean energy
The investment pays back through revenues and avoided costs from grid support, emergency power supply, energy storage, load optimization and power balancing, and of course, the impact on businesses by being a sustainable enterprise with 0g CO2 emissions is beneficial.

It is robust and therefore suitable for use in remote areas and in harsh conditions.

[3] https://sdgs.un.org/goals

SDG 8 Decent work & economic growth
For example AVATAR will help existing fossil fuels oriented ICE (industrial combustion engine), generator and CHP (combined heat & power) manufacturers to prepare their organizations and manufacturing processes to convert to hydrogen powered systems. Their existing sales networks will be helpful to successfully introduce and market the solution worldwide.

SDG 9 Industry, innovation and infrastructure
Zero-emission vessels contribute to sustainable industrialization and decent work for all. It also gives a boost to micro, small and medium-size enterprises after the fossil era. Longer lifetime and better accessibility of 0g CO2 solutions also support local manufacturing and service businesses.

SDG 11 Sustainable cities and communities
The zero-emission vessel feels at home in sustainable city applications. Local energy systems and local grids are keeping the power balanced and forms an essential component of the modern energy system that is also linked with mobility. Smart control and new business models automatically lead to an even higher degree of energy efficiency and optimized use of renewable energy.

SDG 12 Responsible consumption and production
The zero-emission vessel will not be in need of more raw materials and will consume the overstock of recycled raw materials. This way, the continuous supply of raw materials is guaranteed allowing a proper scale up as demand will increase.

SDG 13 Climate action
The very essence of the zero-emission vessel is to overcome global warming resulting from CO2 emissions.

SDG 15 Life on Land
Protect, restore and promote sustainable use of terrestrial ecosystems, sustainable managed forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
The zero-emission vessel reduces nitrogen emissions.

SDG 17 partnerships for the goals
Partnerships to implement the zero-emission vessel could be vital to reduce costs. Governments could play an essential role in this as it can act as a supportive actor.

3.2 Results

3.2.1 Results of SWOT & PESTEL

An extensive SWOT & PESTEL was set up to address the strengths, weaknesses, opportunities & threats of the implementation of (highly) autonomous zero-emission vessels for city freight distribution. Each element is than assigned to a factor of the PESTEL (political, economic, social, technological, environmental or legal).

It is thus a hybrid version of a SWOT & PESTEL in one overview.

Below are the main findings described:

Strengths:
Expelling heavy road transport resulting in increased traffic fluidity and reduction in CO2 and noise reduction is one of the most important strengths. Another important strength is the wide array of applications such as people transport, parcel delivery, garbage collection, logistic support during construction works, events and so on. This enables new business models which can lead to sustainable solutions on the long term. Most importantly, it is a sustainable transportation choice, especially on the long term.

Weaknesses:
An important weakness is the needed infrastructure to implement this, such as power supply & docking which will automatically need investments by public services and cities. Another weakness that cannot be neglected is the risk of collision and obstacles that the zero-emission vessel may encounter on its trajectory. Also the charging time & loading/unloading installations have to be taken into account as well as the last mile trajectory. Tides and currents also have to be taken into account as it could negatively influence the trajectory.
Legal issues such as the ability to have the autonomous zero-emission vessel insured play also an important role.

Opportunities:
As for opportunities, there is the profitable story on the long term with the existence of a low emission zone. Europe and the different regions will continue to enforce measures regarding CO2 reduction, so being ahead of schedule will definitely pay off on the long run. Linking energy flows & the variety of activities that is possible with the highly autonomous zero-emission vessel can also be seen as an opportunity.

Threats:
Possible threats are how much sailing time actually can be done, increasing electricity prices, black outs, how long will the batteries hold and maneuverability of the vessel. If the goal is to obtain short term profits, it will not achieve the desired results and thus form a threat. Lack of a coherent vision and no commitment of stakeholders can also be seen as a threat.

3.2.2 Ranking of the top 10 measures or topics

Based on the results of the SWOT & PESTEL analysis, every item could be linked to a specific measure that will strengthen a city's ability to implement inland waterways distribution via zero-emission autonomous vessel. In total, 10 general measures were identified based on the input of the SWOT & PESTEL analysis.

The top 10 measures have been ranked in a top 10, based on a workshop with AVATAR project partners. This provides an overview of which measures are an absolute must have (hard measures) and which are good to have (soft measures). Below, a ranking can be found with 1 being the most important and 10 the least important, but good to have. Furthermore, each measure is explained what it implies.

1. CASE approach
2. Highest safety level
3. Compatible solutions
4. Waterway city distribution as first choice
5. Committed politicians, authorities and private companies
6. Zero CO2 city center
7. No traffic jams
8. Sustainable silent city
9. Multipurpose city distribution vessels
10. Smart solutions

First of all, if the city has no waterway, then for obvious reasons it is not possible to implement (highly) autonomous zero-emission vessels for inland waterways distribution. That is why every case should be approached in a case-by-case approach.

The first three of the ranking (1,2 & 3) are absolutely must have measures to be able to successfully implement the (highly) autonomous zero-emission vessel for inland waterways distribution.

The next three of the ranking (4,5 & 6) are not absolute must haves, but will play a significant role whether the implementation will succeed.

The last four of the ranking (7,8,9 & 10) are the so called soft measures or good to have measures. These will not play a significant role into whether the implementation will succeed,

but it will ensure synergies with the other measures. These measures will lead to more efficiency. Implementing all these measures will for no doubt pay off on the long run.

3.2.2.1 CASE approach

Modern green transport & energy solutions should be approached in a local context and assessed on a CASE-BY-CASE basis rather than in general spreadsheets, as was the case in the past. This implies that if something worked out in another city, it will not automatically mean it will work out in your city (in other words, there is no “one size fits all” solution).
In several modern cities in the EU, the existing waterways will be used as much as possible for urban distribution.
This does not only include parcel services and delivery of shop supplies, but also construction projects in low emission zones, garbage collection, event supplies, ferry and shuttle services, etc. are eligible.

3.2.2.2 Highest safety level

An inventory list has to be made that enlist all the possible dangers the zero-emission vessel can encounter in its trajectory. Examples are bridges, depth of water, width, tourism on the water, other boats and so on.

3.2.2.3 Compatible solutions

Compatible solutions are needed to reduce costs of the working zero-emissions vessels. Infrastructure for power supply and docking is needed to optimize the efficiency of the vessel. Also loading and unloading installations ensure a fast movement of goods carried by the vessel.

3.2.2.4 Make waterway urban distribution the first choice of all stakeholders.

Sustainable cities and climate change are the issues that politicians should focus on. They should work towards:

- Waterway urban distribution as part of an urban mobility plan.
- Expel heavy road transport from the city center.
- Encourage Corporate Social Responsibility (SDG’s). Socially responsible companies will select sustainable solutions.
- Legislation facilitating urban waterway distribution by, for example creating exception areas from which other types of distribution are banned.
- 0g CO2 emission commitment.

Not only politicians, but also companies and all other stakeholders should work towards a more sustainable community. Socially responsible companies should implement urban waterway distribution as part of all urban transport solutions by exploring new business models complementary to other sustainable businesses in the city center.

3.2.2.5 Committed politicians, authorities and private companies

Being committed will for obvious reasons play a significant role as infrastructure for example will be needed to implement inland waterways city distribution. The project will be a profitable story on the long term which indicates that a long term commitment is needed. The wider picture should be considered instead of focusing on short term profits only.

3.2.2.6 Head towards a zero CO2 emission city center

There should be headed to abandoning the CO2 emitting transport. Electric mobility is key here, but:

- Electrical vehicles and electrical boats require important charging infrastructure and need power at all time.

- It is a major challenge to distribute the electrical GREEN energy to the charging stations in the city. In order to avoid grid congestion and in order to maximize energy efficient use of RES, it is recommended to integrate the charging stations into local smart grid solutions offering the highest energy efficient solution.
- A very interesting way to reduce CO2 emissions is using the urban waterways for distribution of all kind of goods that need to be brought into or to be transported by electric powered vessels out of the city.
- It is clear that the combination via the urban waterways needs to be combined with sustainable last mile delivery.

3.2.2.7 Eliminate traffic jams

The problem of traffic congestion is perhaps the most visible to any citizen. It restricts our freedom and is responsible for huge bills due to waiting times that ultimately have to be borne by the consumer. Keeping trucks out of the city traffic streams and making use of the empty water space for urban city distribution will reduce this.

Reducing traffic jams will also improve the competitiveness of Europe's economy, leading to significant benefits said Kristian Heberg, an official at the European Commission's transport directorate (Carroll, 2021).

3.2.2.8 Build sustainable cities

Sustainable Development Goal 11 is applicable on this, titled as "sustainable cities and communities".
Using waterways for distribution in the city center opens up space on the public roads for safe cycling, smoother public transport in the city and reduced pollution.

3.2.2.9 Multipurpose urban distribution vessels

By expelling heavy road transport, more space is left in the city and more room can be made for relaxation and "green". This can result in streets forbidden for vehicles or closed off streets for playing children after school and in the weekends. The vessels used for urban distribution can be used in a multifunctional way to provide logistical support for events or for recreation.

3.2.2.10 Smart solutions (itinerary)

Making use of an existing logistics app to calculate the time of transportation would be a good idea to implement, but it must be taken into account that the zero-emission vessels have to charge their batteries. Other factors should also be taken into account, such as the trajectory for example.

3.3 Discussion

This guide’s purpose is meant for cities wanting to implement inland waterways distribution via zero-emission autonomous vessels. If there is no inland waterway in your city then for obvious reasons this guide will not be applicable. But, there are many other factors that need to be taken into account if a city is willing to implement the autonomous zero-emission vessels for inland waterway distribution that are not so obvious. That is how this guide serves it purpose, as these non-obvious factors are highlighted and explained.

This guide will not only help determine if a city can actually implement the autonomous zero-emission vessels, but it also provides the information to create synergies, to increase efficiency and to succeed on the long term.

4. Use case selection

4.1 Use case Ghent

The objective of this chapter is to develop and apply a methodology to select a use case for the City of Ghent.

4.1.1 Use case selection methodology Ghent

Based on the market review, it is clear that already a number of use cases can be identified. Within AVATAR it was not possible to investigate them all in detail, therefore it was necessary to select the most promising use cases for a specific city. Therefore, a methodology is used (Excel tool) for Ghent and will be described below, based on Figures 1 and 2.

A description of each potential use case can be included in the columns C-D.

The ranking of the potential use cases is based on a scoring system (from score 0 to 10) for different criteria (Figure 2). The criteria are a combination of project specific topics and economic specific topics. Specific topics relate to the fact whether it will be possible to investigate the use case in detail during the AVATAR project period,. Economic specific topics relate to the probability of an economic interesting case.

Criteria are based on literature review, interviews with stakeholders, alignment with project partners and the AVATAR SWOT/PESTEL analysis. Some of the elements in the SWOT/PESTEL are not included in the use case selection, when they apply to all use cases (and are as such not distinctive). In case a criterium has the same score for all use cases, it doesn't make sense to include this criterium.

Starting point for the use case selection is that the city is known. We are not considering a choice between a use case in Ghent and Hamburg.

What is not included? General characteristics per city, determining whether or not the concept of highly autonomous vessels can be applied in a city (e.g. "is there water in the city"). We start from the assumption that a use case selection is linked to one city. We are not performing a use case selection where we have to choose also between 2 cities. We choose a use case for Ghent and we will choose a use case for Hamburg.

For example, there is a difference in the characteristics of the infrastructure of the cities Ghent and Hamburg. But the characteristics of the infrastructure in Ghent will not determine the use case selection in Ghent; the characteristics relate to all use cases in Ghent. That's also the reason why criterium 3 (below) is not considered in the calculations.

- *AVATAR specific topics:*
    - Criterium 1: The possibility to investigate the use case in detail during the project period (including a pilot case)
    - Criterium 2: The challenge of the use case to be developed in practice (is it a difficult use case to organize versus a straightforward and easy use case)
    - ~~Criterium 3: Transferibility of the use case to other cities (Ghent specific case or not)~~

    - Criterium 4: The support of the use case to the general idea of AVATAR
- *Economic specific topics:*
    - Criterium 5: Volume potential of the use case (does the use case lead to a high amount of shift from road to waterways)
    - Criterium 6: Are the private stakeholders interested in the use case?
    - Criterium 7: Are the public stakeholders interested in the use case?
    - Criterium 8: Complexity of final last mile (Are the number of final destinations limited (e.g. 1 final destination per trip versus several destinations per trip)) (difficulty of getting to final destination)
    - Criterium 9: Complexity of (un)loading
    - Criterium 10: OPEX (additional operational costs per use case?)

Besides these criteria, additional exclusion criteria can be included. For example, if one of the stakeholders that is needed to carry out the use case is not cooperating (e.g. refusal) this will lead to a direct exclusion of the use case.

The rankings should be seen as a general guideline, to make priorities during the project. Based on practical experiences during the project, it might still be possible that rankings will change.

Important to remind is that the use cases are based on the flows entering the city. After selection of an appropriate use case, the appropriate return flow can be determined.

Figure 4.1 Use case selection – general framework of the methodology

B	C	D	E	F	G	O	P	Q	R	S	T	U
				Scoring of criteria (0-10)					Scoring exclusion criteria (0=inclusion; 1=exclusion)			
	Title Use Case	Description Use Case	Involved stakeholders	Criterium 1	Criterium 2	Criterium 10	Weighted scoring	Ranking	Exclusion criterium 1	Exclusion criterium 2	New weighted scoring	Final ranking
				Fill in column	*Fill in column*	*Fill in column*						
Use Case 1	111						0	1	0	0	0	1
Use Case 2	222						0	1	0	0	0	1
Use Case 3	333						0	1	0	0	0	1
Use Case 4	444						0	1	0	0	0	1
Use Case 5	555						0	1	0	0	0	1
Use Case 6	666						0	1	0	0	0	1
Use Case 7	777						0	1	0	0	0	1
Use Case 8	888						0	1	0	0	0	1
Use Case 9	999						0	1	0	0	0	1
Use Case 10	000						0	1	0	0	0	1

Source: own composition

Figure 4.1 shows the different criteria used in the methodology, the weight and description of each criterium, and also the interpretation of the scoring values 0 to 10.

Figure 4.2 Use case selection – overview of criteria

		Weight of each criterium		Description of each criterium	The higher the value,...
AVATAR specific topics	**Criterium 1**	5		The possibility to investigate the use case in detail during the project period (including a pilot case)	the higher the possibility.
	Criterium 2	5		The challenge of the use case to be developed in practice (is it a difficult use case to organize versus a straightforward and easy use case)	the higher the challenge.
	Criterium 3	0		Transferibility of the use case to other cities (Ghent specific case or not)	the higher the transferibility
	Criterium 4	5		The support of the use case to the general idea of AVATAR	the higher the support
Economic specific topics	**Criterium 5**	20		Volume potential of the use case (does the use case lead to a high amount of shift from road to waterways)	the higher the potential volume
	Criterium 6	10		Are the private stakeholders interested in the use case?	the higher the interest of private stakeholders
	Criterium 7	10		Are the public stakeholders interested in the use case?	the higher the interest of public stakeholders
	Criterium 8	15		Complexity of final last mile (Are the number of final destinations limited (e.g. 1 final destination per trip versus several destinations per trip)) (difficulty of getting to final destination)	the lower the complexity of the final last mile
	Criterium 9	15		Complexity of (un)loading	the lower the complexity of (un)loading
	Criterium 10	15		OPEX (additional operational costs per use case?)	the lower the OPEX
		100	ok		
	Exclusion criterium 1	Not all crucial stakeholders are interested in the use case			
	Exclusion criterium 2	Not yet determined			

Source: own composition

4.1.2 Selected use cases Ghent

Potential use cases for Ghent are listed in Figure 3, based upon the market review and interviews with private and public stakeholders. For each use case, a scoring of criteria has been included.

Figure 4.3 Use case selection Ghent – potential use cases, scoring and ranking.

				Scoring of criteria (0-10)											
	Title Use Case	**Description Use Case**	**Involved stakeholders**	**Criterium 1**	**Criterium 2**	**Criterium 3**	**Criterium 4**	**Criterium 5**	**Criterium 6**	**Criterium 7**	**Criterium 8**	**Criterium 9**	**Criterium 10**	**Weighted scoring**	**Ranking**
				Fill in column	*Fill in column*		*Fill in column*	*Fill in column*	*Fill in column*	*Fill in column*	*Fill in column*	*Fill in column*	*Fill in column*		
Use Case 1	111	Delivery of construction sites (B2B)	TBD	10	8		10	9	10	10	9	7	7	8,65	1
Use Case 2	222	Delivery of shops (horeca, retail) (B2B)	TBD	7	9		7	10	6	7	7	5	5	7	3
Use Case 3	333	Parcel delivery (e-commerce) (B2C)	TBD	6	9		7	10	6	7	5	5	5	6,65	5
Use Case 4	444	Delivery of government buildings (office equipment) (B2G)	TBD	8	7		8	7	7	8	6	6	6	6,75	4
Use Case 5	555	Delivery of short chain products (B2B)	TBD	8	7		7	7	7	8	7	5	5	6,55	6
Use Case 6	666	Delivery of flowers (B2B)	TBD	8	7		7	7	7	7	7	5	5	6,45	7
Use Case 7	777	Delivery of building wholesalers (B2B)	TBD	10	7		10	9	10	10	9	7	7	8,6	2
Use Case 8	888	Delivery of cobblestones (B2G)	TBD	6	6		9	6	7	8	8	5	5	6,45	7

Source: own composition

Based on the methodology above, it is possible to make a ranking of the different use cases. As such a priority list can be set up from high to low. In case time and budget is available, focus will be on all use cases. When selections have to be made, this will be done on the basis of the ranking. Five groups can be distinguished: construction materials (including delivery of construction sites and building wholesalers), horeca (including short chain products), retail (including flowers), delivery of government buildings and parcel delivery.

The following ranking will therefore be used in the AVATAR project (= use case selection city of Ghent):

1. Construction materials
    a. Delivery of construction sites
    b. Delivery of building wholesalers
2. Horeca (also including short chain products)
3. Retail (also including flowers)
4. Delivery of government buildings
5. Parcel delivery

4.2 Use case Hamburg

The insights and data related to the use cases for Hamburg have been elaborated in close cooperation of the AVATAR project and the WaCaBa (Water Cargo Barge) project[4].

The following two chapters therefore, deal with the development and identification of possible use cases that are relevant for the AVATAR project at the Hamburg site. Together with the Fraunhofer CML who worked on their WaCaBa feasibility study, the Logistics Initiative Hamburg organized stakeholder workshops to find potential stakeholders who have an interest in carrying out transport by waterway in the future. With the help of the Logistics Initiative Hamburg network, member interviews were conducted and feedback gathered in a hands-on approach to find well-fitting stakeholders to develop and implement a Hamburg use case within the AVATAR-project.

4.2.1 Use case selection methodology Hamburg

The methodology of the use case selection in Hamburg was not based on a scientific basis or assumptions; rather it was a very practical approach as mentioned in the introduction. The aim was to set up a pilot project, which is supported by strong corporate partner, who also believes in a successful implementation. As a result and therefore as a starting point for the involvement of potential users, the following sectors were identified: CEP service providers, the construction industry, waste disposal companies, the catering and hotel sector, as well as trade and industry. Altogether, through the contact with the workshops and the interviews, two possible use cases, with the help of two member companies of the Logistics Initiative Hamburg were developed into follow-up pilots or projects.

4.2.2 Selected use cases Hamburg

Two use case partners could be acquired for piloting in different scenarios in Hamburg. Both located in the eastern part of Hamburg in the district of Billbrook and City Süd. The identified areas in detail will be described in detail in the next chapter. The first use case partner, the German parcel service provider DHL - Deutsche Post in the Billbrook district and the second use case partner TOP Mehrwert - Logistik, a logistics service provider that is located in the City Süd. The DHL use case that was developed within the framework of the AVATAR project will now also be part of the new EU funded project DECARBOMILE[5], which started in September 2022 and aims to innovatively improve green last mile logistics in Europe.

The key pain point, for last mile delivery in city centres are non-existing or expensive retail spaces for micro hubs, the goal of the pilot by using the AVATAR urban vessel is, to either transport parcels or e-cargo bikes from the DHL distribution centre to the city centre. For this, the barge should be used as a “floating & temporary micro hub” from which the e-cargo bikes can directly be loaded or start from the barge directly, before they got loaded in the distribution centre of DHL. The detailed study area of Billbrook in the east where the parcel distribution centre of DHL for Hamburg is located will be part of the next chapter 5 which is called Market study for selected use cases.

[4] Fraunhofer CML, WaCaBa feasibility study, 2021
[5] DECARBOMILE Project, Logistics Initiative, 2022

Together the City of Hamburg, the Logistics-Initiative Hamburg, Opleidingscentrum Hout & Bouw (OHB), the Technical University of Hamburg (TUHH) and Deutsche Post – DHL are the key stakeholders which are involved within the project for the ***Use Case 1: Parcel delivery***.

Hamburg Logistik-Initiative Hamburg Deutsche Post DHL HOUT& BOUW OPLEIDINGSCENTRUM TUHH Technische Universität Hamburg

The second use case with TOP Mehrwert-Logistik as a partner for a pilot which was developed, is part of the InnoWaTr project, which is currently is in the application process and aims to develop innovative and sustainable inland waterway applications & a modal shift based on cooperative "Freight Flow Coalitions".

As mentioned above the TOP Mehrwert company is also located in the eastern part of Hamburg (City-Süd). The plan for piloting a barge, is to supply the shopping center "Westfield Hamburg-Überseequartier" which is directly located on the Elbe river in the district of the HafenCity. With over 200 retail units including gastronomy, hotels and a cruise terminal, it is planned to be opened in the last quarter of 2023. Currently, a delivery and disposal transports are mainly planned to be carried out via road transport. The details of the study area will be described in the next chapter.

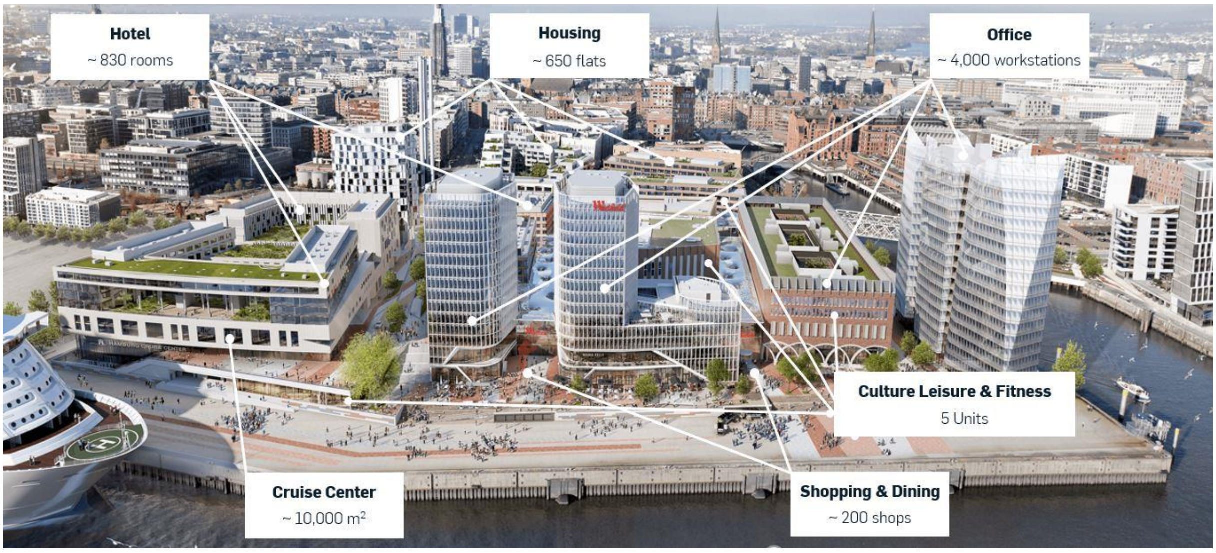


Figure 4.4: Westfield Hamburg-Überseequartier, Source: www.ueberseequartier.de

The four key stakeholders, which are involved within the project for the Hamburg ***Use Case 2: Retail supply***: TOP Mehrwert-Logistik, Logistics-Initiative Hamburg (LIHH), Opleidingscentrum Hout & Bouw (OHB) and The KLU (Kühne Logistics University).

TOP MEHRWERT-LOGISTIK Logistik-Initiative Hamburg HOUT& BOUW OPLEIDINGSCENTRUM THE KLU KÜHNE LOGISTICS UNIVERSITY

5. Market study for selected use cases

The purpose of this document is to give an overview of the context in which Ghent urban freight distribution is applied. This is based on available statistics and on existing studies applied to Ghent. As such, supporting material is collected for the economic assessment analysis for different use cases: delivery of construction sector, retail and horeca, government buildings and parcel deliveries.

In this chapter we start with a general description of the City of Ghent (5.0), followed by a demarcation of the study area for the AVATAR use cases (4.1). Characteristics of the study area are included in section 5.2. A distinction has been made between the identification of general freight transport flows in the study area (5.2.1) and the available waterway infrastructure in the study area (5.2.2). In section 5.3 a selection of characteristics of the use cases in Ghent have been made (based on available statistics and/or existing studies). Section 5.3 has been divided into an identification of commercial activities in the study area (5.3.1), describing the potential demand for the construction sector (5.3.1.1), retail and horeca (5.3.1.2), government buildings (5.3.1.3) and parcel deliveries (5.3.1.4). In 5.3.2 main characteristics of logistics for the use case are included. Section 5.3.3 includes a description of the characteristics of the vessels.

5.1 Ghent

General description of the City of Ghent

A general description of the City of Ghent is based on Vlaamse Provincies (2023a,b), Ghent (2023a,d,e), NBB (2022) and Vervoerregio Gent (2020). Figures selected have an effect on potential freight flows and demand for the different use cases.

The city of Ghent is the provincial capital of East Flanders (Belgium) with 267.712 inhabitants in 2023. Figures 5.1 and 5.2 show the location of the City of Ghent.

The city of Ghent has an area of 157,96 km². Figure 5.3 shows the number of inhabitants per km² in 2022 (Vlaamse Provincies, 2023). The highest numbers are situated in the inner city of Ghent.

The wealth index in Ghent equals 103, meaning that the income and wealth level is higher that the national, Belgian average.

An important part of the city of Ghent entails a part of North Sea Port, named North Sea Port Flanders (Belgian port site of the merged North Sea Port, stretching from Vlissingen on the North Sea coast in the Netherlands to Ghent in Belgium). North Sea Port Flanders is the main Flemish port for dry bulk. Direct employment accounts for 28.877 in 2020.

Table 5.1 shows the numbers of commuting traffic in the City of Ghent, making a distinction between incoming commuting, outgoing commuting and local employment in the city of Ghent.

Table 5.1. Incoming, outgoing and local employment in the city of Ghent

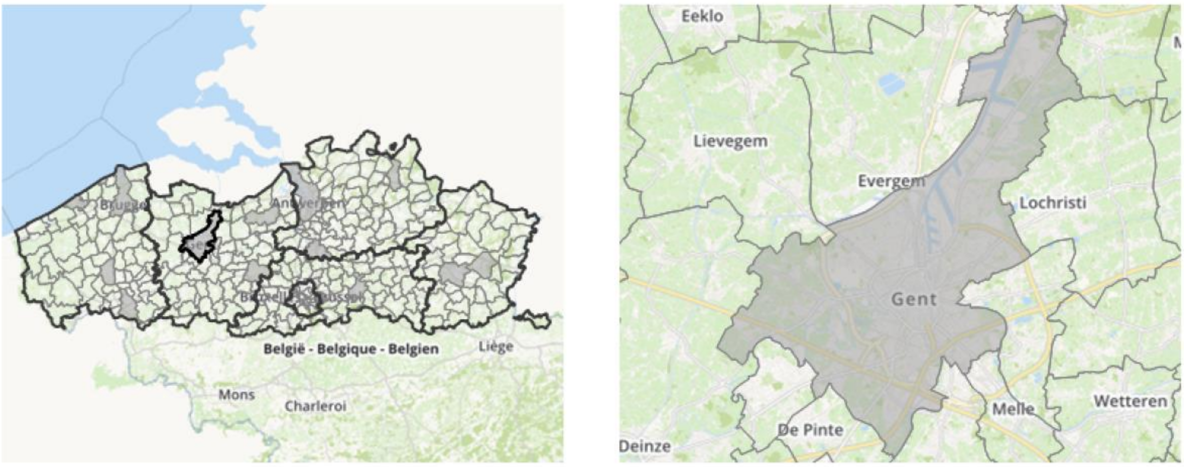
	2012	2017	2019
Incoming commuting	96.850	106.148	110.046
Local employment	49.465	57.364	60.409
Outgoing commuting	39.650	39.343	40.739

Source: Vlaamse Provincies (2023b)

Figure 5.1: Location of City of Ghent

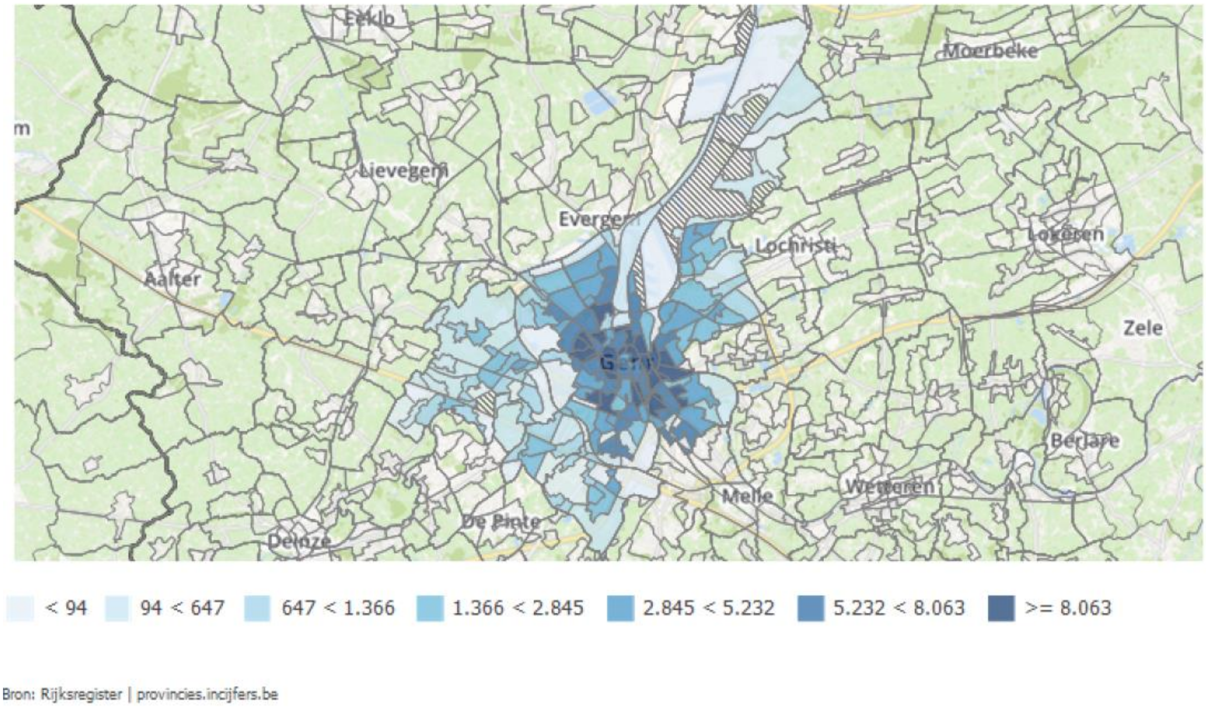
Source: Google maps (2023)

Figure 5.2: Location of City of Ghent



Source: Vlaamse Provincies (2023a)

Figure 5.3: Number of inhabitants per km² in City of Ghent



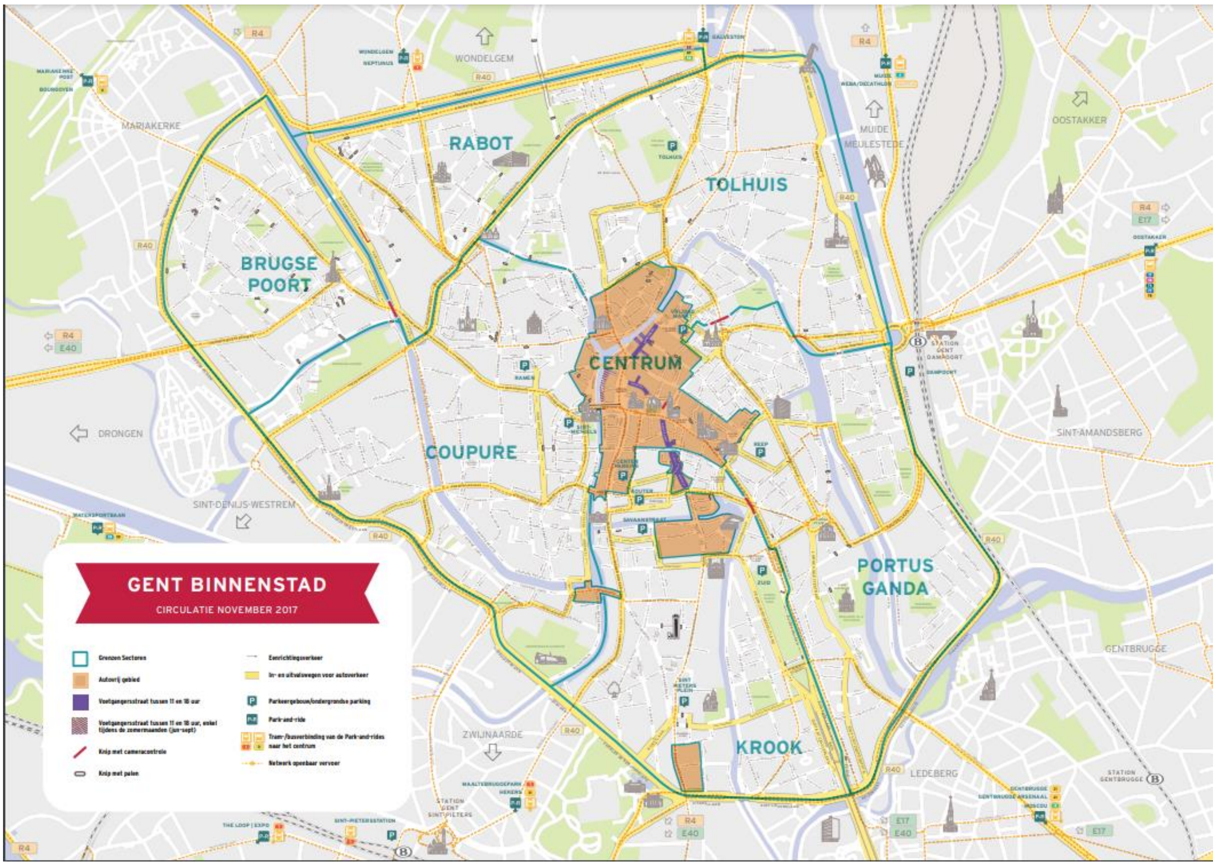
Source: Vlaamse Provincies (2023a)

In Flanders, the ambition is to create zero-emission freight transport (under the umbrella of the Green Deal of Urban Logistics, also signed by the City of Ghent). As such, actions are already taken to green the fleet of vehicles. This is part of the solution, but will not solve issues of traffic intensity and safety in a city center. As such, delivery of goods via waterways might be part of the solution, making use of distribution hubs at the border of a city. Bike cargo services are also relevant here, but will not be able to move all type of goods. On top of this, consolidation of goods in a hub create extra costs and time loss.

In Ghent, a circulation plan and car-free zone has been introduced in 2017 (see Figure 4.4), restricting transit flows in the city center of Ghent. (Ghent, 2023b) In 2020, a low emission zone has been introduced, making sure that the most polluting cars are not allowed anymore in the city center. (Ghent, 2023c) As such, loading and unloading is restricted in some areas between 11.00 and 18.00.

Gent Levert (www.gentlevert.be) has the ambition to be the facililtator making it possible that city freight distribution will be organized in a more efficient and sustainable way.

Figure 5.4: Circulation plan and car-free zone in the City of Ghent

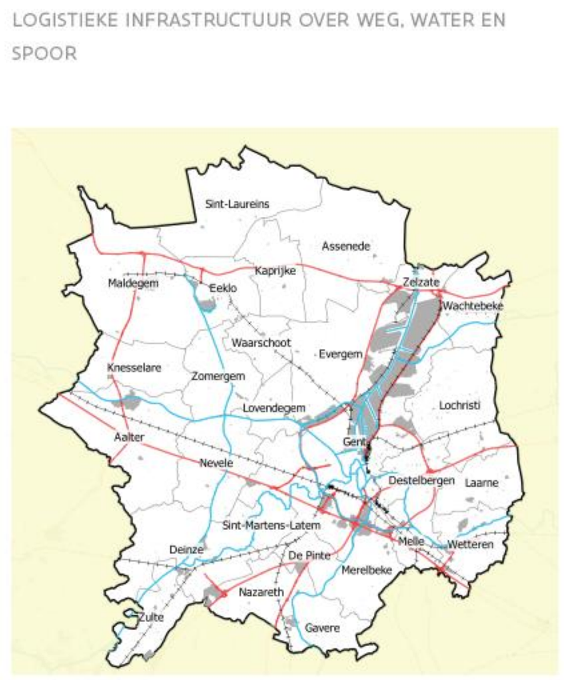


Source: Gent (2023b)

The city of Ghent is part of the “Vervoerregio Gent”. In Figure 5.5, the logistics infrastructure is shown. The region is characterized by 3 main highways (indated in red): E34 (Northern part of the region), E17 (Antwerp-Moeskroen, passing via the South of Ghent) and E40 (Liège – Veurne). Besides the highways, Ghent is connected with several national N-roads (N60, N9, N70 and N43). Starting from Ghent, connections for passenger rail transport are available to Antwerp (L59), Kortrijk (L75), Bruges and Brussels (L50 and L50A). In North Sea Port, railway freight connections are available.

Part of the waterways are used for freight transport (Schelde, Leie, Kanaal Gent-Oostende), but some parts are also used for recreational purposes. The Scheldt and the Leie are connnecting the region of Antwerp and the Province of West-Flanders, connected to the Ringvaart and the channel Ghent-Terneuzen. The channel Ghent-Ostend is connecting the Ghent region with Bruges and Zeebruges. (Vervoerregio Gent, 2020) This description illustrates also the potential to link Ghent city freight distribution with long distance traffic flows via inland navigation. Figure 5.6 illustrates the capacity of the waterways in Flanders.

Figure 5.5: Logistics infrastructure in the Ghent region



Source: Vervoerregio Gent (2022)

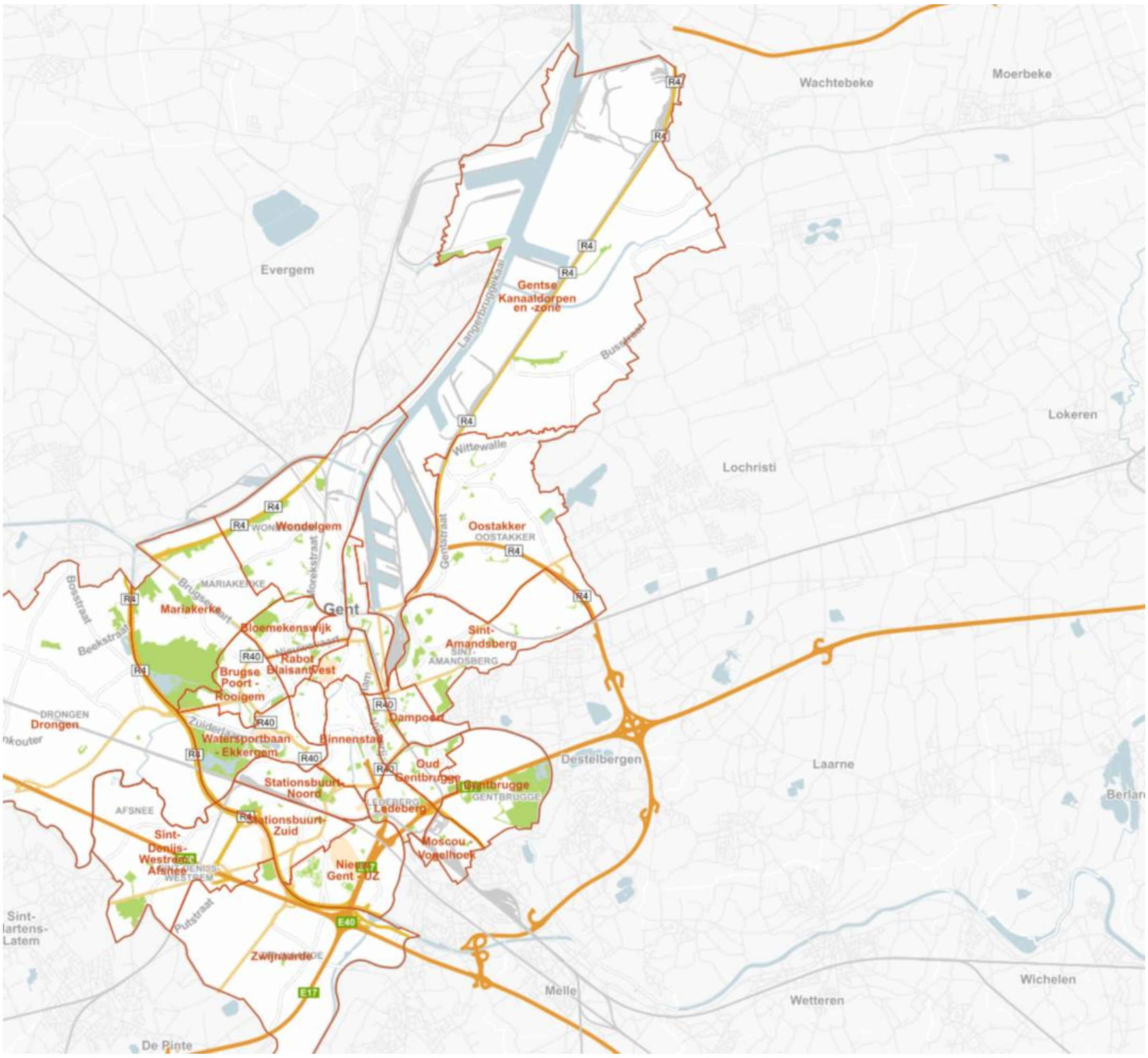
Figure 5.6: Waterways in Flanders

Source: Visuris (2023)

Ghent consists of 25 districts, as shown in Figures 5.7 and 5.8. One of the districts is the “inner city” (“binnenstad”, see here). This district receives more attention in the AVATAR-project, because an important share of economic activities of horeca and retail are situated in that district. Figure 5.9 shows that the “inner city” district encompasses the car-free zone.

The “binnenstad” has an area of 2,66 km² (1,7% of the Ghent area). The “binnenstad” contains 19.163 inhabitants (7% of the Ghent population), with 7.212 inhabitants per km². The wealth index equals 111, higher than the Ghent value of 103.

Figure 5.7: Districts in the City of Ghent

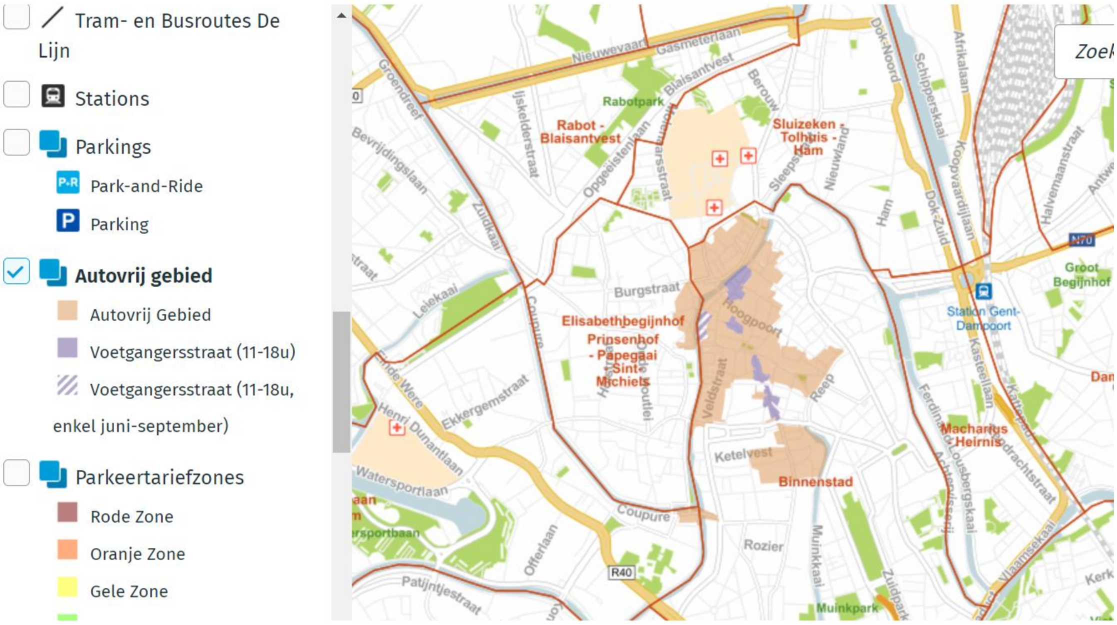


Source: Gent (2023f)

Figure 5.8: Location of district “inner city” (“binnenstad”) in City of Ghent

Source: Ghent (2023f)

Figure 5.9 Car-free zone in the “inner city” of Ghent



Source: Gent (2023f)

5.1.1 Demarcation of the study area in Ghent

The study area in Ghent has been determined in alignment with the existing “vision note” of the City of Ghent and The Vlaamse Waterweg (Figure 5.10). The vision note “Water in de stad Gent” (Stad Gent and De Vlaamse Waterweg, 2019) describes the common view on the future development of waterways in the City of Ghent, taking into account the mix of functions (recreation, living boats,...). City freight distribution has to take into account the role of these different functions. This will also be reflected in the challenges of introducing (highly) autonomous vessels in the city center of Ghent.

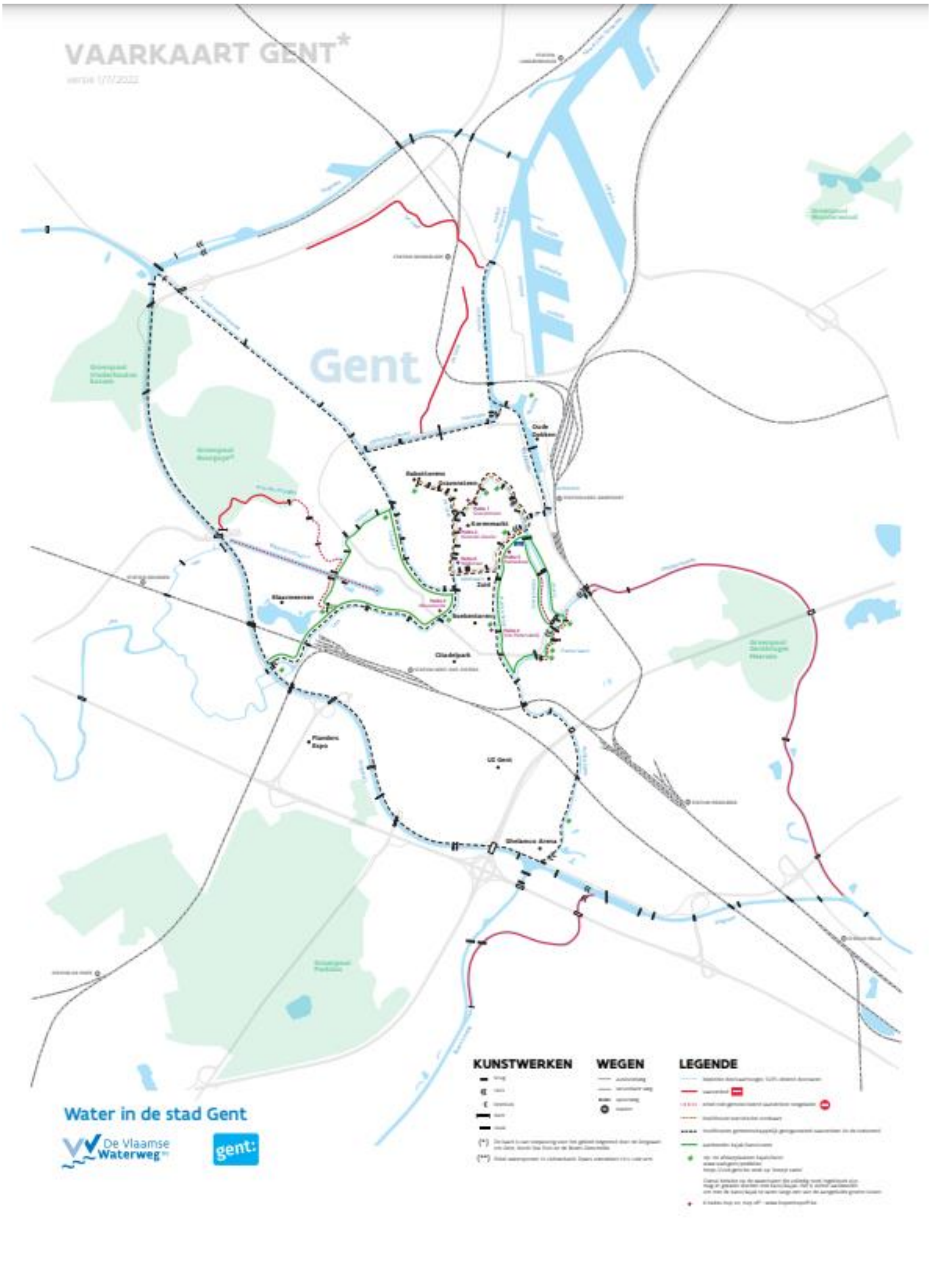
Figure 5.11 shows the sailing map for the City of Ghent. The outer boundary (North, West, South) is the “Ringvaart”, the waterway “ring” around Ghent, connecting the channel “Ghent-Terneuzen” (in the North) with the Leie and The Scheldt. The boundary at the eastern part is the “voorhaven” and “Oude dokken”.

For the construction logistics, AVATAR will focus on all waterways in the city center of Ghent. For horeca and retail, first focus will be on the waterways in the district “inner city”.

Figure 5.10: Visualization of the study area

Source: Stad Gent and De Vlaamse Waterweg (2019a)

Figure 5.11: Sailing map for the City of Ghent



Source: Stad Gent and De Vlaamse Waterweg (2019a)

5.1.2 General characteristics of the study area

5.1.2.1 Identification of General Freight Transport Flows in the study area

In an ideal situation, detailed data on origin-destination flows are available and could be used to determine freight bundling potential locations and the potential to shift goods from trucks to vessels. And thus leading to more efficient city freight logistics. Unfortunately, these data are not available (yet). In times of new concepts of AI, Internet of Things and physical internet, this will be a point of attention for governance. Anyhow, in this chapter we give an overview of available statistics related to freight transport in the context of the Ghent city and region.

VRP (2022) points out the need of setting up virtual and physical platforms. As such, based on shared data, efficiency gains can be obtained for the movement of goods and vehicles. From a governance point of view, a balance should be determined between a fluent delivery of goods and a minimal impact on logistics in a city center. A close cooperation is needed between a city, companies and the logistics sector. Sharing data and infrastructure turns out to be an important bottleneck (VIL, 2020).

Today, freight transport flows are mainly optimized on the level of an individual logistics provider. Imagine two neighbouring shops in the City of Ghent. Shop 1 receives goods from logistics provider 1 and shop 2 receives goods from logistics provider 2. This is creating 2 flows in a city center. It would be more efficient that both flows are combined in one transport flow. This could be done by the means of a neutral distribution hub at the border of a city. This also illustrates the contradictory interests of different stakeholders. (Omgeving Vlaanderen) An example is the project CULT and Amsterdam Logistic Cityhub. A city might consider to provide government buildings for the operation of a distribution hub (e.g. on a temporariy basis, for free or at a lower than market price). (VIL, 2020)

It is assumed that 25% of transport flows (based on kilometers driven) in a city are related to construction logistics, 10% to cooled transport, 10% to facility management, 5 to 10% to parcel deliveries, 5 to 10% to waste transport and 40% is related to general freight and retail. (VRP, 2022) Logistics are assumed to be responsible of 25% of CO2-emissions in cities.

Large companies are characterized with more efficient operations (thus higher loading factors), leading to a less need for using an urban DC.

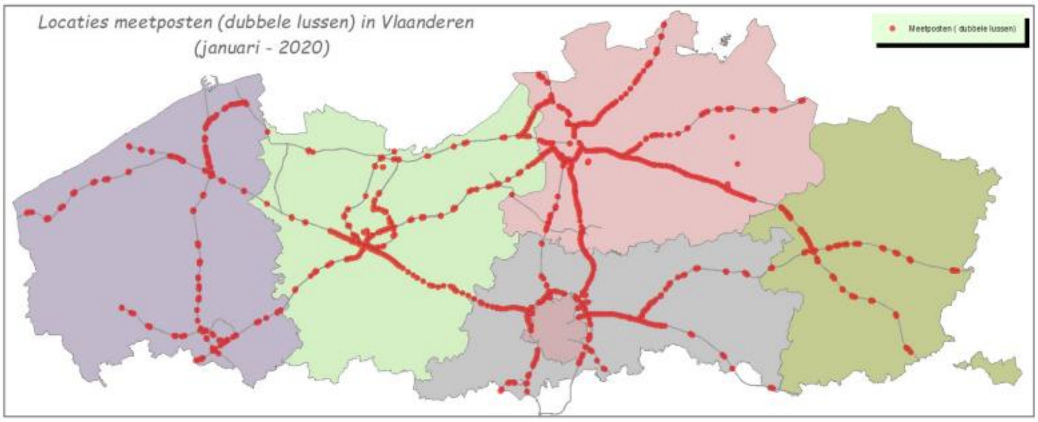
The lack of data makes it also difficult to determine the optimal location of a DC. The location of a DC is determined in relation to the location where the traffic flows are entering the city. Logistic service providers with a low delivery density in the city might have more benefits of using a DC in comparison to logistic service providers with a high delivery density in the city. (VIL, 2020)

Typical methodologies for assessing Freight Transport Flows are based on traffic counts (e.g. pneumatic readers), surveys, camera technologies (e.g. Number Plate Recognition) or data from Construction Logistics Setups (e.g. gate sensors). (Brusselaers et al. 2023). In order to determine the actual performed vehicle-kilometres (vkm) of Heavy Goods Vehichles (HGV) in the city center of Ghent, one might consider to use data from On-Board units. In Brusselaers et al. (2023), a methodology has been presented to assess these vkm (assessing the impact of delivering construction sites). These data are required in order to be able to asses policy measurements. Viapass data doesn't give info about the loading rate of the vehicle.

The main external cost categories (costs that are not compensated by the polluter) for transport are pollution, greenhouse gas emissions, noise pollution, congestion, accidents and infrastructure costs. To calculate external costs, data on trip and vehicle level is required.

In Vlaams Verkeerscentrum (2020), an overview is given of the traffic in Flanders for the year 2019. Reports for the years 2020 and 2021 are also available, but not representative because of the corona-effect. Figures are collected on the basis of traffic counts via detection loops. These figures give an idea about the intensity of the traffic on specific points, but don't give an idea about origins, destinations and load rate.

Figure 5.12: Location of detection loops in Flanders



Source: Vlaams Verkeerscentrum (2020)

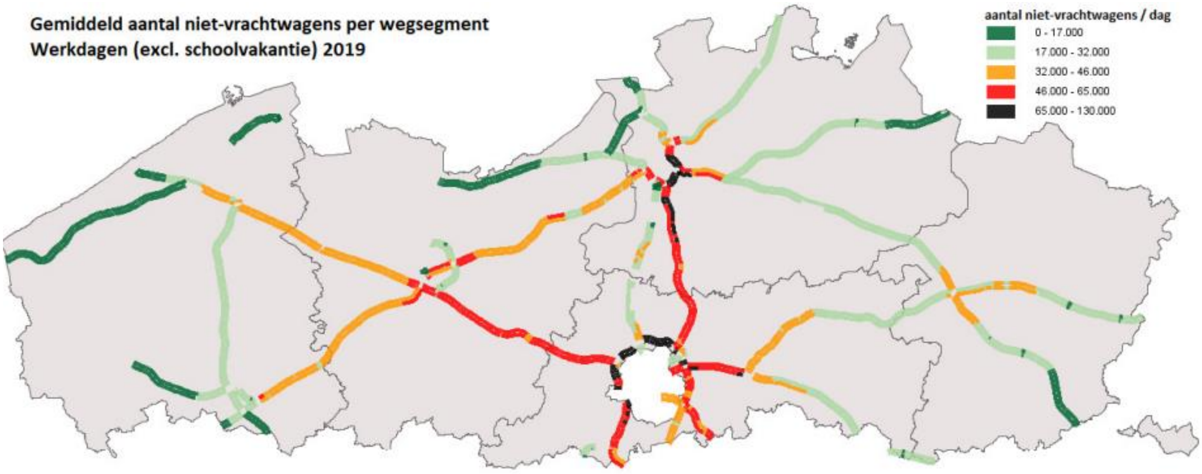
A distinction is made between trucks and non-trucks in Figures 5.13-5.15. Trucks are vehicles longer than 6,9 metres (can be a freight truck, but also a bus). Non-trucks refer to vehicles smaller than 6 metres (can be a passenger cars, but also a van).

Figures based on an average working day (no school holidays), show 10.000 to 15.000 trucks per working day (in both directions) on the E17 Ghent-Antwerp. On the E40 Ostend-Ghent-Brussels, this accounts for 6.000 to 10.000 trucks per working day (in both directions). On the R4 (direction to North Sea port), there are more trucks towards North Sea port (6.000 to 10.000 trucks per working day) compared to trucks from North Sea Port (3.000 to 6.000 trucks per working day).

The highest intensity of non trucks is located at the Eastern part of Ghent (46.000 to 65.000 non-trucks per working day; both directions), and on the E17 direction of Ghent (from Antwerp) with 46.000 to 65.000 non-trucks.

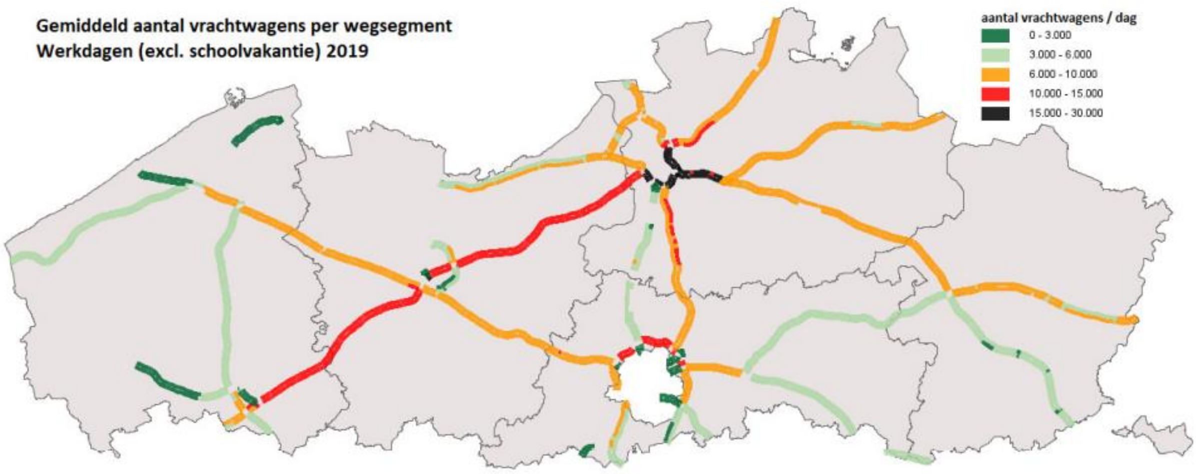
When taking into account both trucks and non-trucks, it is striking that the section on the E40 near Ghent is characterized by a high intensity of use (71.000-150.000 vehicles).

Figure 5.13: Average number of non-trucks per working day (no school holidays) in year 2019



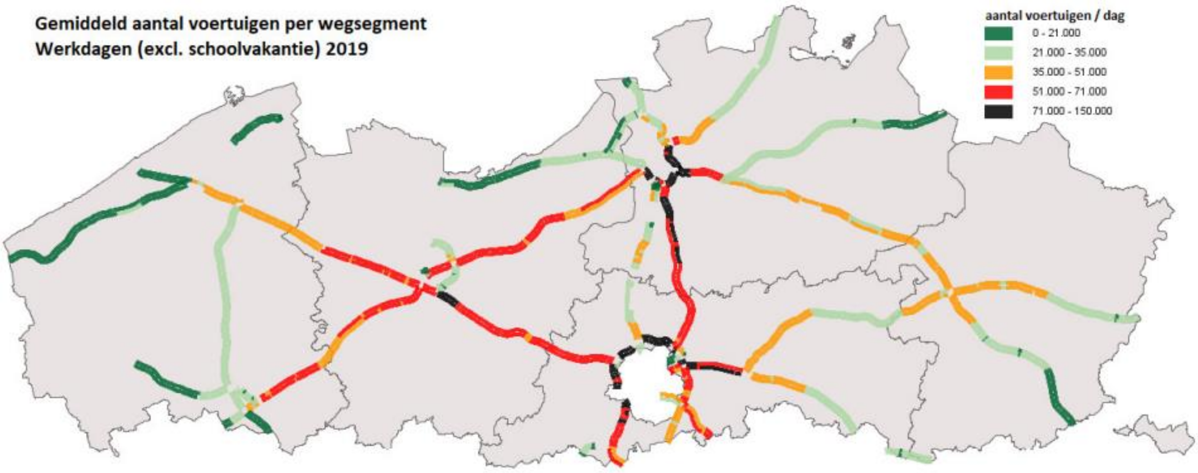
Source: Vlaams Verkeerscentrum (2020)

Figure 5.14: Average number of trucks per working day (no school holidays) in year 2019



Source: Vlaams Verkeerscentrum (2020)

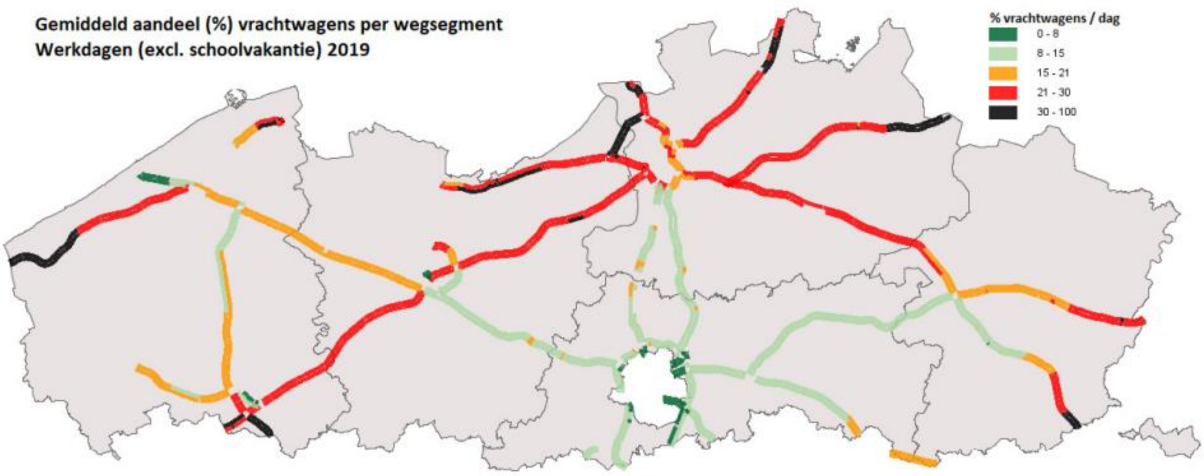
Figure 5.15: Average number of trucks and non-trucks per working day (no school holidays) in year 2019



Source: Vlaams Verkeerscentrum (2020)

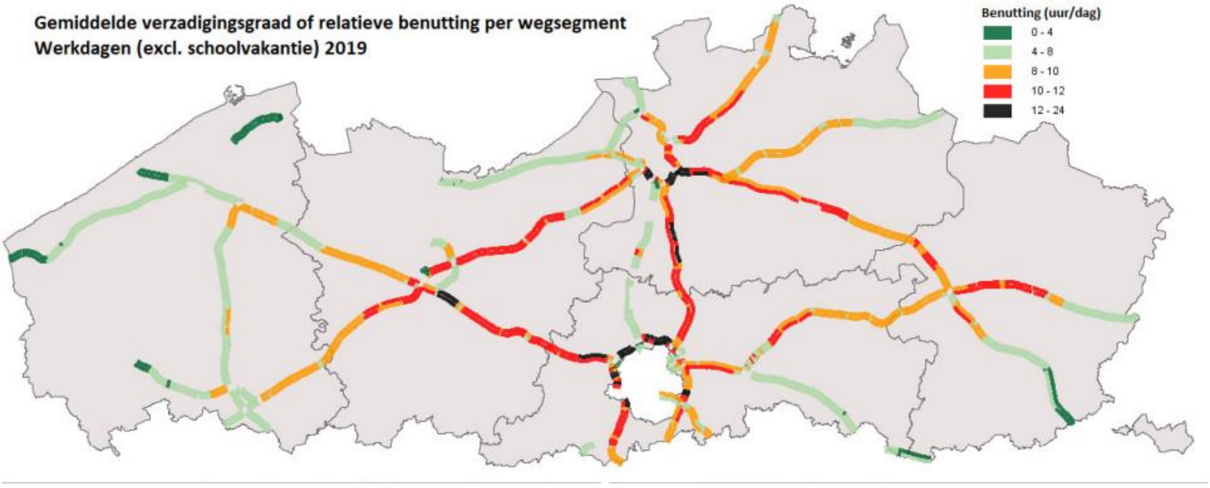
Figure 5.16 shows the share of trucks (trucks versus non trucks). The highest shared are located on the E17 and the R4. In Figure 5.17, the figures give an indication of the used capacity of the highways.

Figure 5.16: Share of trucks per working day (no school holiday) in year 2019



Source: Vlaams Verkeerscentrum (2020)

Figure 5.17: Indication of the used capacity of highways in Flanders (year 2019)



Source: Vlaams Verkeerscentrum (2020)

According to 2017 figures, 4.000 trucks per week pass the pedestrian zone, up to 8.000 trucks in the city center, representing 75.800 deliveries per week. (HLN, 2017)

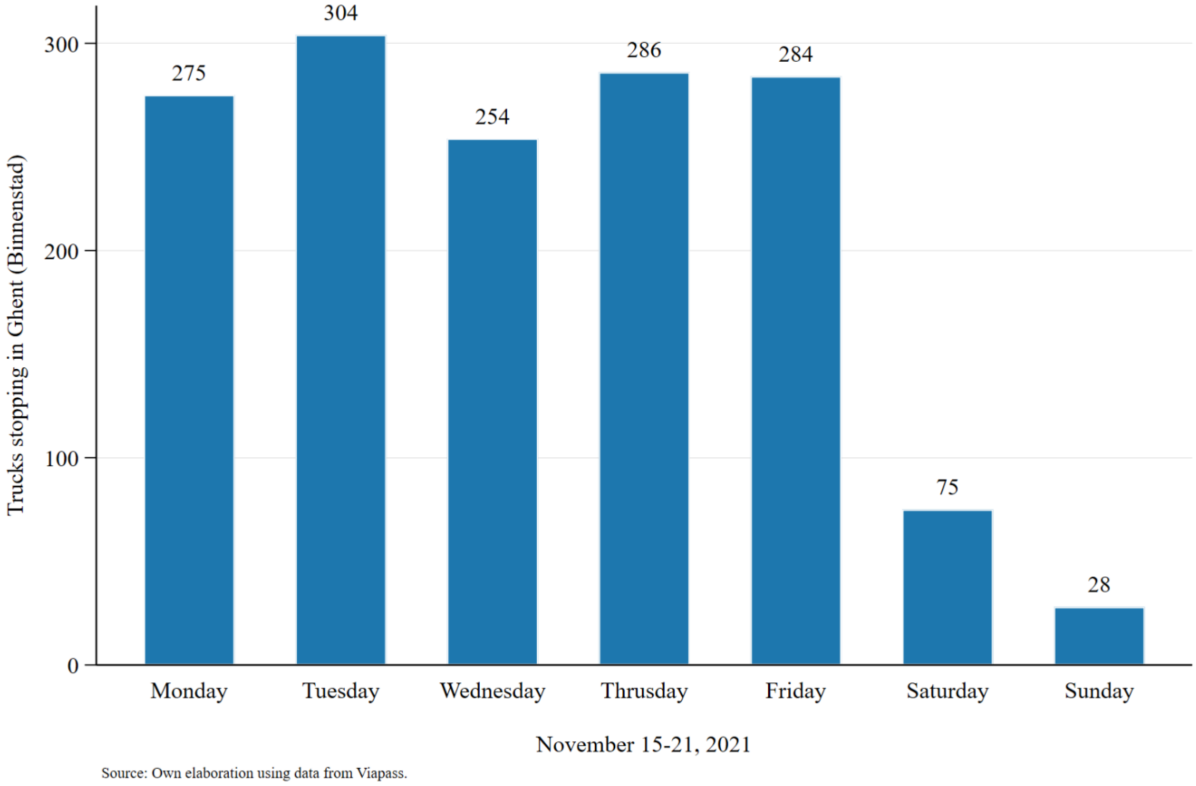
According to Vlaams Verkeerscentrum (2023), around 1.207 trucks and buses enter Ghent daily on a working day via the western part of Ghent (B402; based on 12/2022 figures). A fraction will enter the “inner city” of Ghent.

Based on OBU-data (Viapass), an estimation has been made by University of Antwerp (Department of Transport and Regional Economies) about the number of trucks that stopped (minimum 15 minutes) in the Ghent “inner city” (see Figures 4.18 and 4.19).

Main conclusions are:

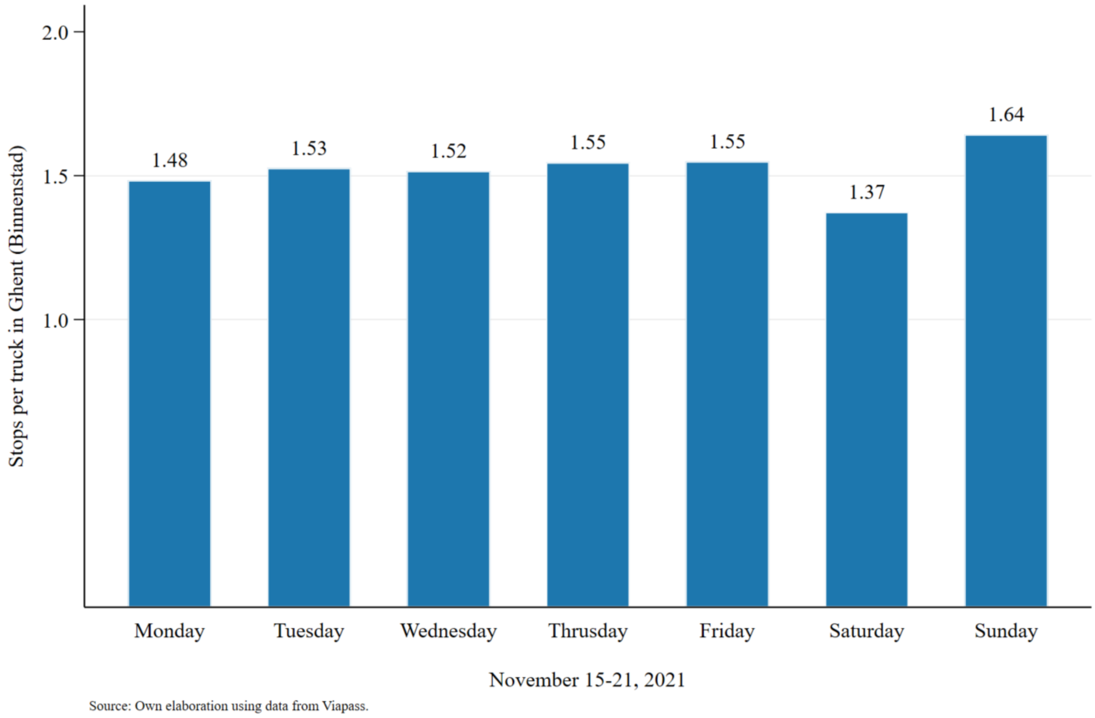
- On average, 281 trucks stopped daily during the business week of November 15-19, 2021;
- The day reporting the highest numer of trucks stopping was Tuesday (304) and Wednesday the least (254);
- The week’s total number of stops was 2.288;
- The amount of stops per truck is relatively stable during the business week (around 1,5).

Figure 5.18: Trucks stopping (minimum 15 minutes) in the "inner city" of Ghent (period 15/11/2021-21/11/2021)



Source: Elaboration of UA/TPR on Viapass data (2023)

Figure 5.19: Stops per truck in "inner city" Ghent



Source: Elaboration of UA/TPR on Viapass data (2023)

A "bevoorradingsprofiel" of a city gives an overview of the characteristics related to urban freight transport. One of the characteristics is an overview of current (and future) freight flows in a city center.

Rebel (2019) created a decision tool for Gent Levert, giving a quantitative overview of freight flows, geographical distribution of flows, number of trips,... Based on the relation between shop floor area and shopping volumes ("distributieprofielen"), a quantitative idea has been calculated. Based on assumptions, transport flows have been quantified (volumes, trips, drops, load carrier, type of vehicle, time of transport, type of logistics service provider). In section 5.3.1, we also include an overview of freight flow characteristics for some use cases.

Figure 5.20: Heat map of horeca destinations and volumes in city center of Ghent

Source: Rebel (2023), Watergebonden stadsdistributie Gent, Klankbordgroep 16 maart 2023.

In the Mobility Plan of the City of Ghent (2015), specific information is included about freight traffic in the City of Ghent, see pages 150-153. A list of potential bundling initiatives are included, such as a distribution hub at the border of the city and construction hubs. Following bottlenecks for freight transport are included:

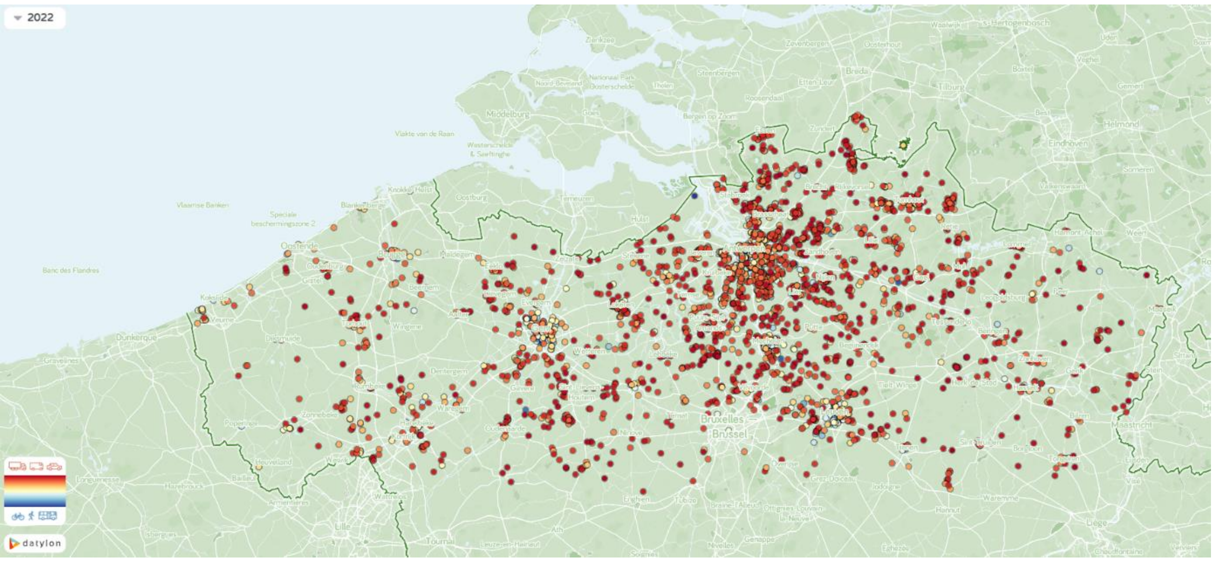
- Dampoort and Port Arthurlaan;
- Zwijnaarde;
- Accessibility of the city center;
- A freight ban on the B401 leads to a burden on the traffic in the south of Ghent.

It has been noted that delivery of goods to retail, horeca and construction wharfs can be carried out (partially) via inland waterways.

On the Flemish level, the Flemish freight model has been developed, see here. Starting from origin-destination freight flows for road transport, inland navigation and rail transport estimations have been made for future freight flows. Data are based on flows between NUTS3-regions (“arrondissementen”) and are therefore not useful for this report.

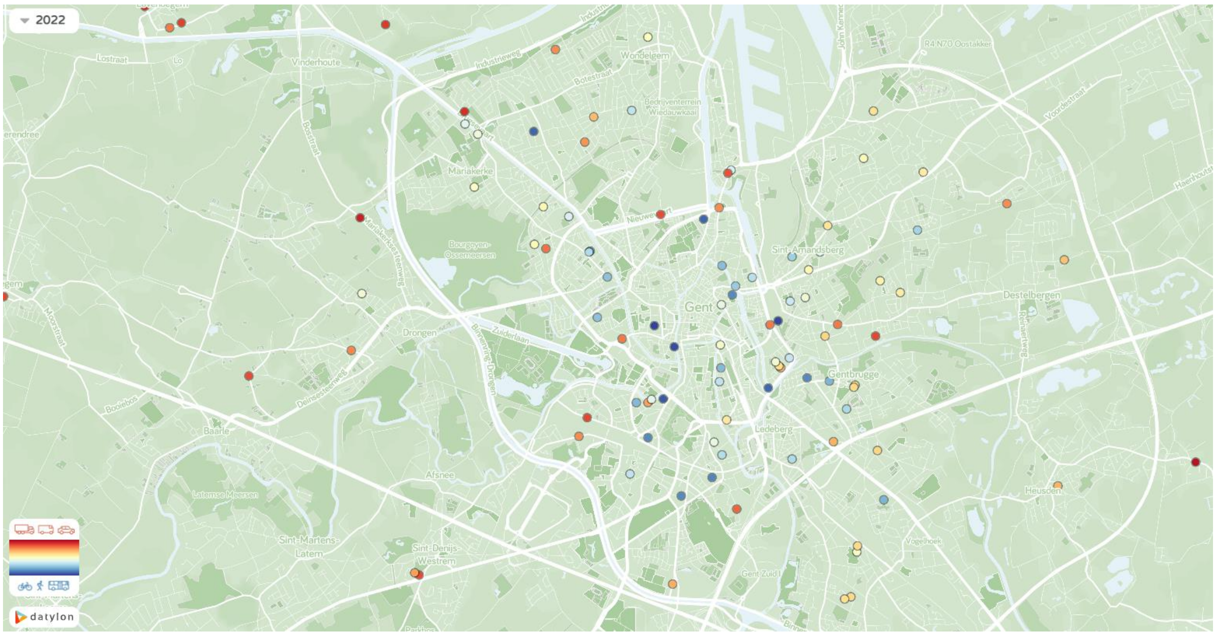
In the “Straatvinken” project, citizens in Flanders counted during one hour the traffic in the street they are living (Figures 5.21 and 5.22).

Figure 5.21: Results year 2022 project “Straatvinken” in Flanders



Source: Straatvinken (2023)

Figure 5.22: Results year 2022 in the City of Ghent



Source: Straatvinken (2023)

The following locations are categorized with a higher level of trucks and passenger cars: Nieuwevaart, Voormuide, Zaamslagstraat, Kasteellaan Anyhow, it should be noted that the datapoints don’t give a representative overview.

5.1.2.2 Infrastructure in the study area

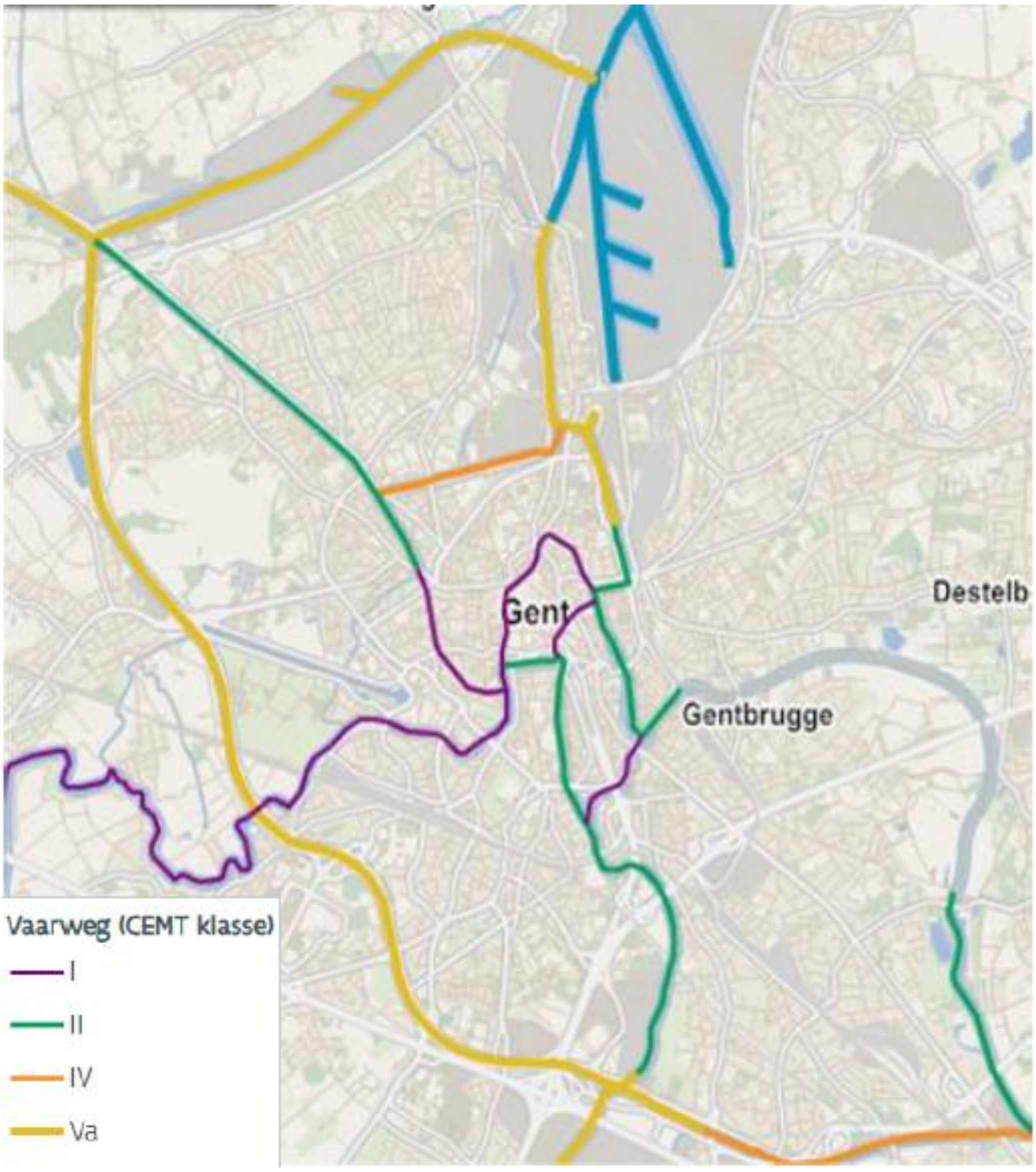
The Ringvaart is characterized as a class Va waterway (1500-3000 ton payload). The city center of Ghent is reachable via the Channel Ghent-Ostend (Class II, 400-650 ton payload) and the channel Ghent-Terneuzen (Class V). From the southern part of Ghent, the city center is also reachable via the Muinkschelde (Class II). In order to get to the inner city, one should take into account that the destination is characterized as a class I waterway (250-400 ton). In practice, payload will be limited to 25 ton payload, as will be described in section 4.3.3 because the study area is characterized with a numer of bridges that have to be passed (limiting the capacity of the vessel). Characteristics are available via www.visuris.be. In section 5.3.2 (Logistics in use per use case), an overview of characteristics of different sailing routes are given.

Figure 5.23: Names of the waterways in the City of Ghent

Source: Stad Gent and De Vlaamse Waterweg (2019a)

Two locations for distribution hubs have been selected. One is located in the Northern part (location: Everstein) and the Southern part (location: Eiland Zwijnaarde).

Figure 5.24: payload capacity per waterway in City of Ghent



Source: Rebel (2023)

Figure 5.25 gives an overview of the waterways in the City of Ghent, including locks, bridges and the two potential DC locations.

🔴	DC1 at the Northern part of Ghent (Everstein)
🟢	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
)(	Bridges (not in use when red)
»	Locks (not in use when red)

Source: own composition based on Visuris (2023)

Operational challenges in Ghent

In Stad Gent and De Vlaamse Waterweg (2019a) an overview is given of the current limitations of the network. Quite a number of bridges are present in Ghent, with a limited vertical clearance (distance from the waterline up to the highest point of the vessel). For example, the Vleeshuisbrug has a vertical clearance of 1,48 metres. Some bridges can be opened in theory, but that is not preferred because of the effect on crossing pedestrians, bikers and car traffic. A number of locks are present, dependent on the selected route one or more locks will be passed and leading to extra travel time and operational limitations (not operational 24/24). The depth of the water (1,6 m) should also be taken into account. Because of interference with passenger traffic, speed will be limited (in case of interaction with passenger transport up to max. 5 km/h).

Besides this, the vessel should take into account pollution in the water; and thus risk for damage. Examples are: bikes, mopeds, floating debris, traffic signalling equipment and garbage containers. These types of pollution could damage the freight vessels. Once a year, the waterway administrator lowers the water level and collects the garbage (see here and here).

Figure 5.26: pollution in the water (garbage container)

Source: picture Tom Pauwels (3/4/2023)

Figure 5.27: pollution in the water

▲ Vissers van de Vlaamse Waterweg halen fietsen en andere rommel uit het water. © Jill Dhondt

Source: https://www.pzc.nl/gent/gentse-binnenwateren-opnieuw-verlaagd-zodat-vissers-fietsen-uit-water-kunnen-halen~a4c370aa2/

There is a variety of quays in the city center. City of Ghent is not in favour of putting cranes on the wall (because of conflicts with the architecture-historic value of the city center. This will limit the economic potential.

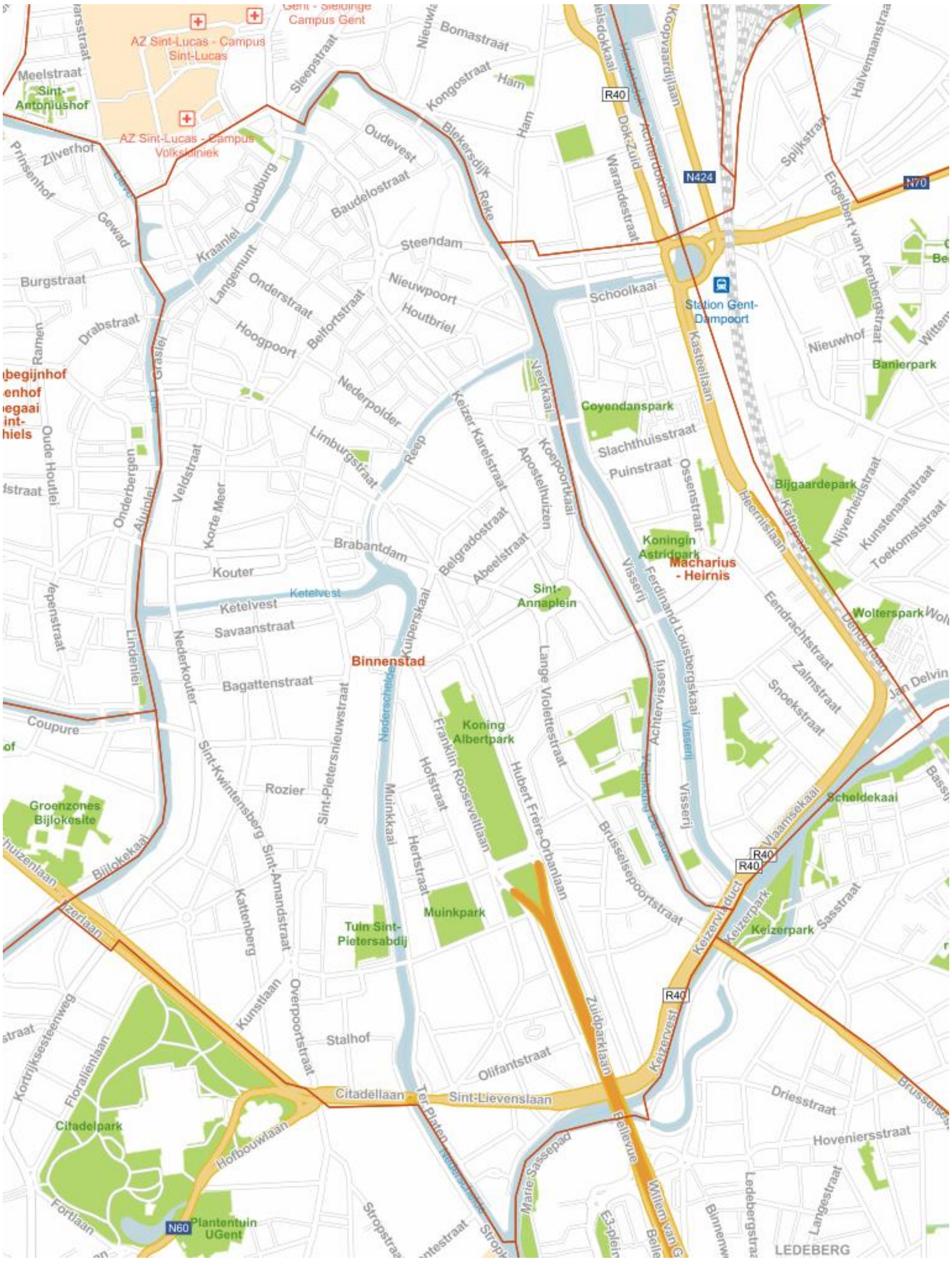
Table 5.2: characteristics of waterways

Klasse	Lengte (m)	Breedte (m)	Diepgang (m)	Hoogte (m)	Laadvermogen (ton)
I	38,50	5,05	1,80-2,20	4,00	250-400
II	50-55	6,60	2,50	4,00-5,00	400-650
III	67-80	8,20	2,50	4,00-5,00	650-1000
IV	80-85	9,50	2,50	5,25-7,00	1000-1500
Va	95-110	11,40	2,50-4,50	5,25-9,10	1500-3000
Vb	172-185	11,40	2,50-4,50	5,25-9,10	3200-6000 (2-baks lang)
VIa	95-110	22,80	2,50-4,50	7,00-9,10	3200-6000 (2-baks breed)
VIb	185-195	22,80	2,50-4,50	7,00-9,10	6400-12000 (4-baks)
VIc	193-200	34,20	2,50-4,50	9,10	9600-18000 (6-baks breed)
VII	195-285	34,20	2,50-4,50	9,10	14500-27000 (9-baks)

bron: DVW

Source: Stad Gent and De Vlaamse Waterweg (2019a)

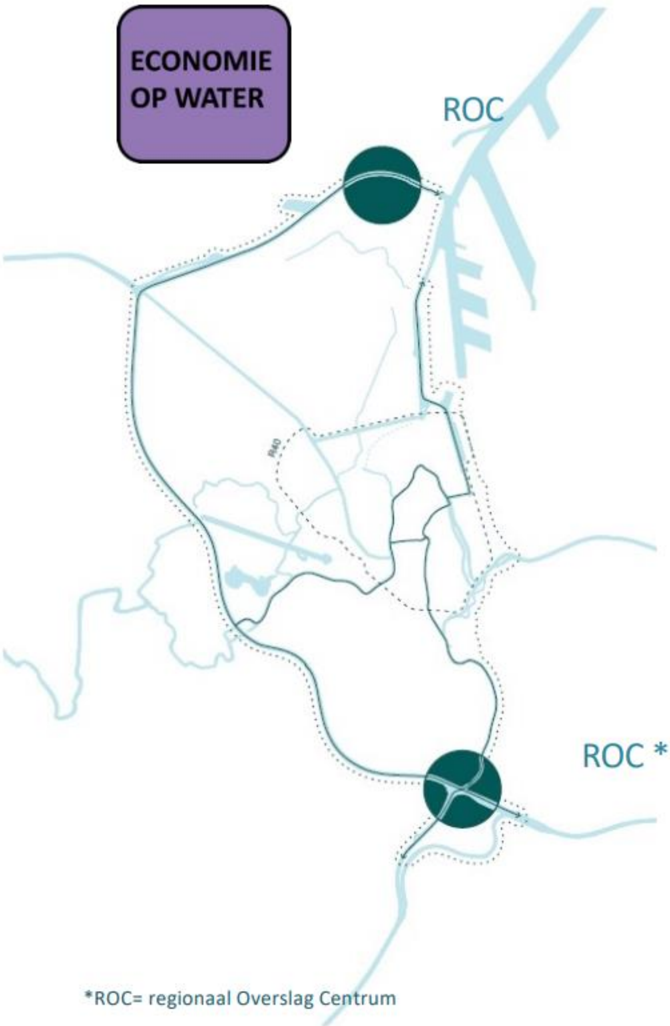
Figure 5.28: Waterways in the district “inner city”



Source: Gent (2023f)

In Stad Gent and De Vlaamse Waterweg (2019), 2 waterbound clusters have been identified and described. Three locations in the southern part of Ghent are identified that could play a role in city freight distribution via the water: Tech Lane Ghent (Eiland Zwijnaarde), Alinso-site in Zwijnaarde and E3-sluis/UCB. In the Northern part of Ghent, locations are identified alongside the Ringvaart. See also

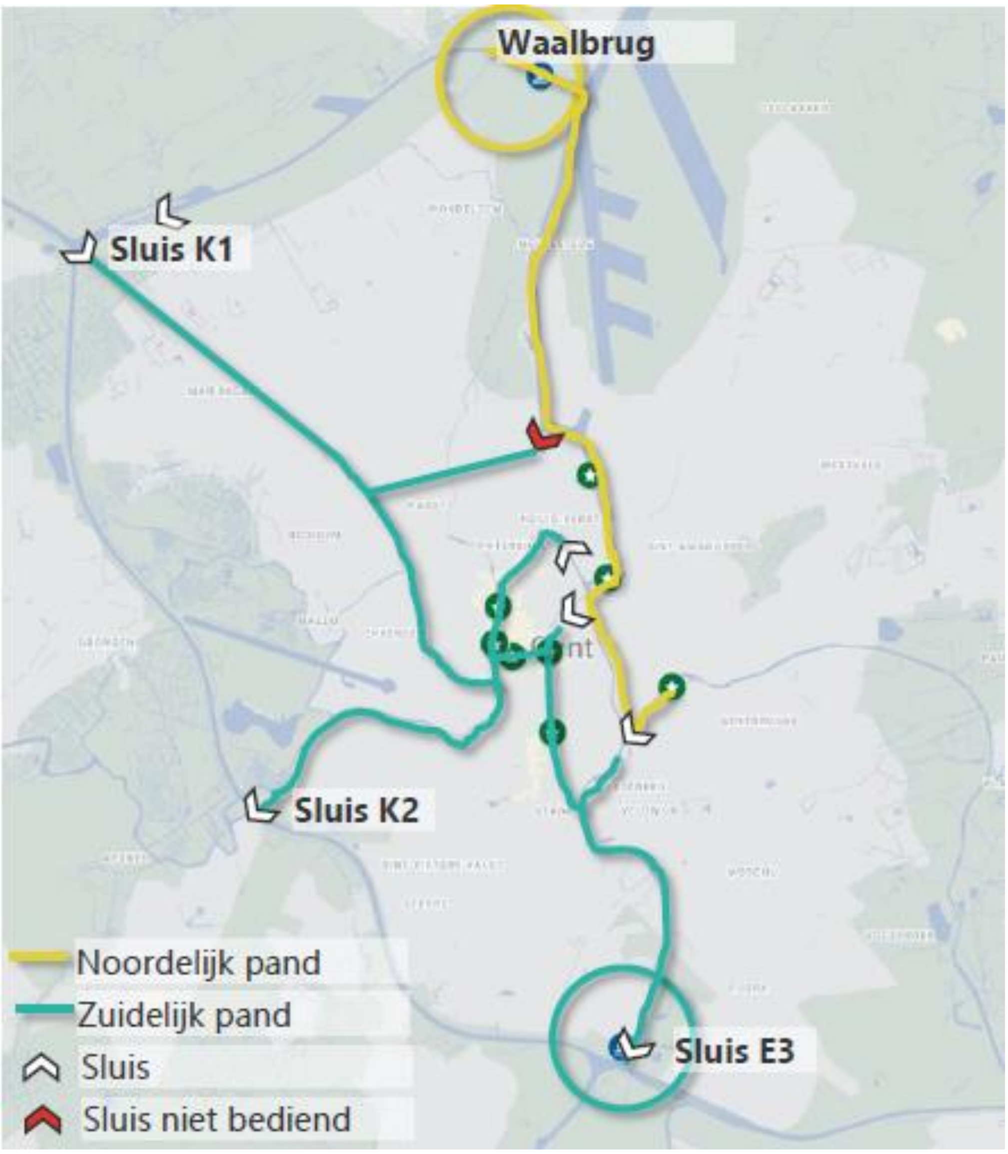
Figure 5.29: Waterbound clusters in Ghent (potential locations for DC's)



Source: Stad Gent and De Vlaamse Waterweg (2019b)

In alignment with Rebel (2023), the AVATAR-study focuses also on the potential of a Northern DC and/or a Southern DC. This is also illustrated in Figure 5.30.

Figure 5.30: Potential DC's

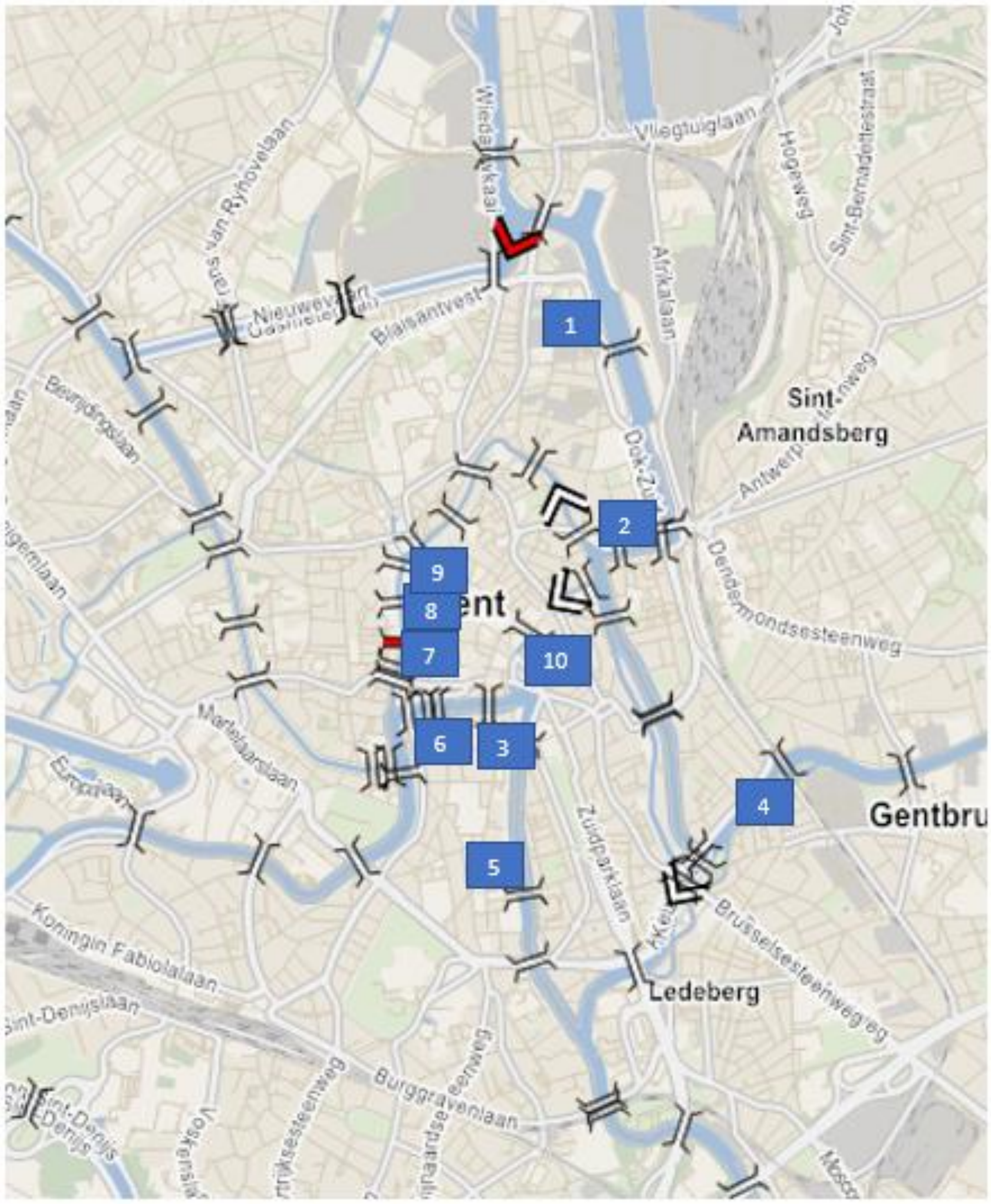


Source: Rebel (2023)

Loading and unloading locations in the City of Ghent

In Figure 5.31 the potential (un)loading locations in the City of Ghent are indicated. These locations will be the focus of horeca and retail freight flows in this study. For construction logistics, it should be noted that loading and unloading might also depend on the location of the wharf, meaning that locations not listed on the map are also possible (see figure 5.32 and here).

Figure 5.31: Potential (un)loading locations in the City of Ghent



(Un)loading locations. 1=Handelsdok; 2=Hagelandkaai; 3=De Krook; 4=Sluis Gentbrugge; 5=Muinkkaai; 6=Ketelvest; 7=Koophandelsplein/Kuipgat; 8=Predikherenlei; 9=Graslei; 10=De Reep

Source: own composition based on Visuris (2023)

Figure 5.32 Test Green Wave in Ghent

(c) Sandra Leroy - Unloading the Green Wave in the city of Ghent

5.1.3 Specific characteristics use cases

In AVATAR focus is on following use cases: construction logistics, delivery of horeca and retail, facility services and parcel deliveries.

When determining the potential demand of flows, it should be noted that many logistics service providers already have an efficiently organized delivery process (with high load factors). Convincing them to use neutral, open hubs will be a challenge. It might be assumed that from a cost perspective, these companies can't be convinced. From a governance point of view, a city might consider to think about imposing rules for city freight distribution.

5.1.4 Identification of commercial activities in the study area

5.1.4.1 Construction sector (description of potential demand)

In general, construction logistics account for 20 to 35% of total urban freight traffic in the EU or 20 to 30% of transported tonnages, but it is hard to determine the actual performed vehicle-kilometres in a city center. (Brusselaers et al., 2023)

In order to determine the actual performed vehicle-kilometres (vkm) of Heavy Goods Vehichles (HGV) in the city center of Ghent, one might consider to use data from On-Board units (GPS-based trackers for vehicles above 3.5t driving in Belgium). This is referred to as Viapass-data. In Brusselaers et al. (2023), a methodology has been presented to assess these vkm (assessing the impact of delivering construction sites). These data are required in order to be able to asses policy measurements. Construction-related vehicles and transport flows are derived from the Viapass-data, making it possible to trace the entire route in a city center (origin-destination matrices on vehicle and day level).

In future research it might be interesting to do a similar research for the city of Ghent.

In a city environment, the storage area on wharf is limited combined with the difficult accessibility. This means that delivery of material will mainly be based on just in time deliveries. An increase in the total number of renovations also lead to more and smaller logistics flows. By using a building hub at the border of a city, logistics can be organized in a more efficient way by introducing consolidation and economies of scale; in combination with milkruns. As such, one building hub can supply different wharfs in a city. This might also include pre-assembling activities at a building hub and 24/7 opening hours. From an operational point of view, one might opt for a neutral operation of the building hub (not dependent on one producer of building trader). Further more, it has been estimated logistics costs represent 8-12% of the total project cost. The project concludes that total logistics costs can decrease with 42% when using a building hub. (VIL, 2020b)

Specifically for Ghent, this might include full truck loads or vessels (from producers or wholesalers) towards a building hub, followed by milk-runs via the water to different wharfs in the city.

In order to assess the number of wharfs in the City center of Ghent an analysis has been carried out of the environmental permits (“omgevingsvergunning”).

The total number of requests for environmental permits in the City of Ghent account for 3.876 (year 2021), of which 2.452 were approved. (Gent, 2023e)

An analysis has been made of building permits in the “inner city” of Ghent. Building permits refer to buildings, renovations, demolitions, felling trees, placing billboards,…

Two types of analysis have been performed. First, focus was on the permits inside the geographical boundary of the “inner city”. Secondly, focus was on the permits close the waterways in the “inner city”, taking into account 50 m left and right from the middle of the waterways in the “inner city”.

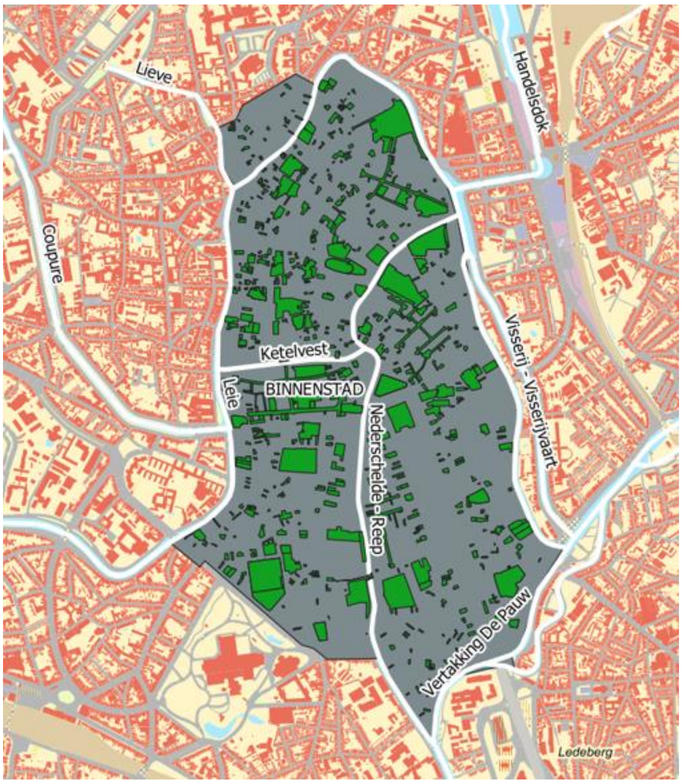
Permits inside the geographical boundary of the “inner city”

In the period 11/2017-03/2023, 820 building permits have been issued by the City of Ghent. An overview is shown in Figure 4.33. In the year 2022, 170 building permits have been issued.

Permits close to the waterways in the “inner city”

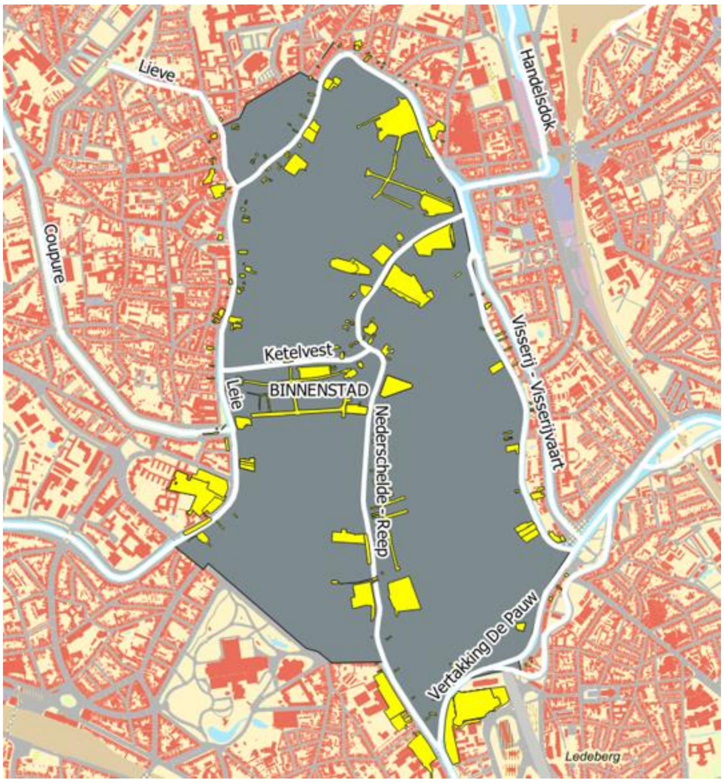
In the period 03/2018-03/2023, 278 building permits have been issued by the City of Ghent. An overview is shown in Figure 4.34. In the year 2022, 53 building permits have been issued.

Figure 5.33 Building permits in the "inner city" of Ghent (period 11/2017-03/2023)



Source: own analysis based on City of Ghent

Figure 5.34: Building permits located close to the waterways in the "inner city" (03/2018-03/2023)



Source: own analysis based on City of Ghent

In Table 5.3, an overview is included of some recent and planned waterbound wharfs in the City of Ghent.

Table 5.3 Overview of recent and planned waterbound wharfs in the City of Ghent

- Bond Moyson, Vrijdagmarkt 10 – aan de Leie
- Technologiecampus Bargiekaai
- Hoek Rodetorenkaai - Hagelandkaai (Rodetorenkaai 5-7)
- Portus
- Inno (?) Vlaanderenstrata – achterzijde Leie
- De Nieuwe Dokken verkaveling Zuidveld (5 loten waarvoor OMV al is verleend)
- Rinkkaai: openbaar onderzoek lopende, uiterste beslsiingsdatum 22/8

OMV_2022154780

- Stropkaai Broeders van Liefde, openbaar onderzoek lopende, uiterste beslissingsdatum 17/10

OMV_2021096882

- Sint-Lievenslaan, Onderzoek naar volledigheid bezig

OMV_2023052896

- Loskaai GKA4: momenteel in voorbespreking

Source: Gentse Dienst Stedenbouw en Ruimtelijke Planning

5.1.4.2 Retail and horeca (description of potential demand)

As an effect of corona, there has been an accelarated evolution towards omni-channel. Meaning that shops are servicing the client via several channels (as well physically as online). Besides this, pure online market players kept on growing. Telecommuting (and thus an effect on local shopping) has also an effect on the attraction of shops in a city center. Cities (and shops) were confronted with a shift in visitors because of changes in the characteristics of commuting and the effect of corona on tourism. On top of that, the location policy for shops outside the city center puts an extra pressure on shops in the city center (Vlaamse Provincies, 2023a)

Retail is defined as companies or shops providing physical goods to the end consumer. Horeca are hotels, restaurants and cafés.

Figures below are based on Vlaamse Provincies (2023a), Locatus (2023) and Gent (2023e). Locatus makes yearly an overview of all selling points in Flanders (type of activity, location, and shop floor area).

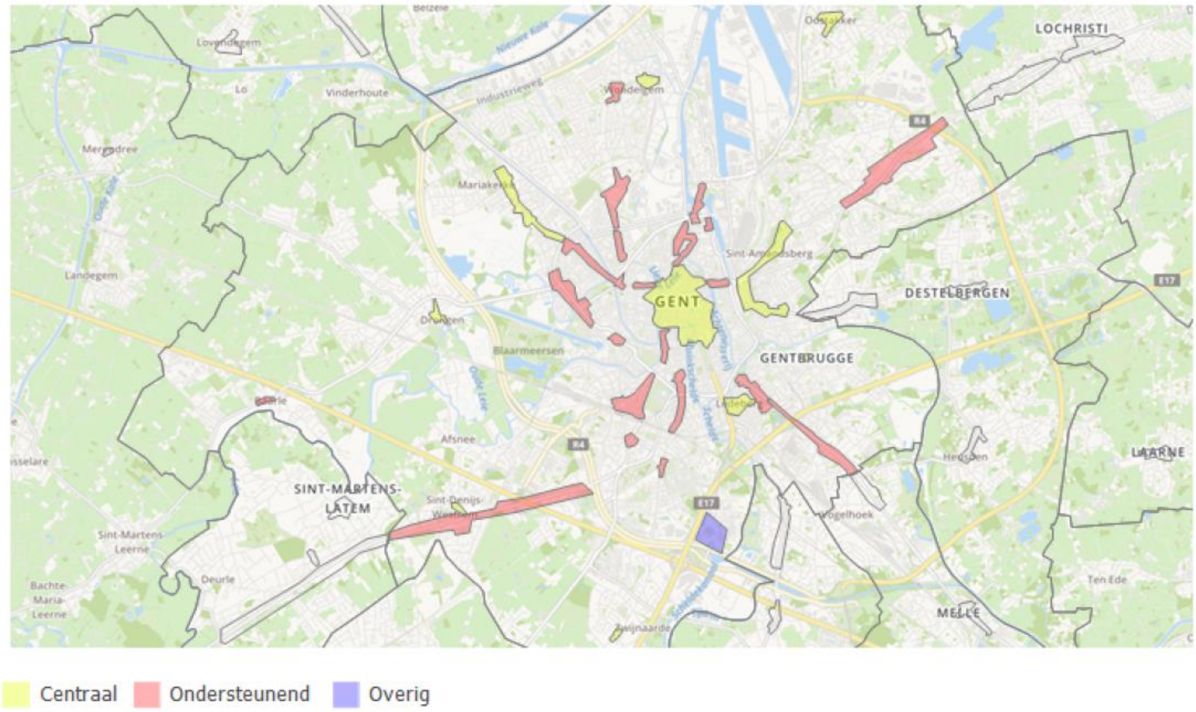
In Ghent, a total of 5.548 commercial properties are counted in 2022, of which 4.900 in use and 648 not used. This includes 529.099 m² shop floor area (466.140 used as shops and 62.959 not used or under renovation). As such, 88% of the commercial properties are in use.

The number of 5.548 commercial properties can be split up into 2.036 shops, 1.429 horeca locations, 1.435 consumer related services, 628 empty locations and 20 locations under renovation. In this study we focus on the shops and horeca locations.

In Figure 5.33 the area of the city of Ghent has been divided into central shopping areas (most important shopping areas), supporting shopping areas and other. The central shopping areas consist of 861 shops (about 140.000 m²) in 2022.

In the AVATAR use cases, focus will be on the central shopping area (yellow area with indication of “Ghent”).

Figure 5.35: Shopping areas in city of Ghent



Source: Vlaamse Provincies (2023a)

In the retail sector, 2234 persons are self-employed and 6849 persons are salaried in the City of Ghent. In horeca, these figures are respectively 1822 and 3803 in the year 2021. (Vlaamse Provincies, 2023a)

In the AVATAR use cases for horeca and retail, focus will be on the “inner city”.

In the “binnenstad”, a total of 1.750 commercial properties are counted in 2022, of which 1.520 in use and 230 not used. This includes 126.029 m² shop floor area (103.636 used and 22.393 not used). As such, 86% of the commercial properties are in use.

In the “binnenstad”, 677 shops and 583 horeca locations are counted, representing 33% of the Ghent shops and 41% of the Ghent horeca locations.

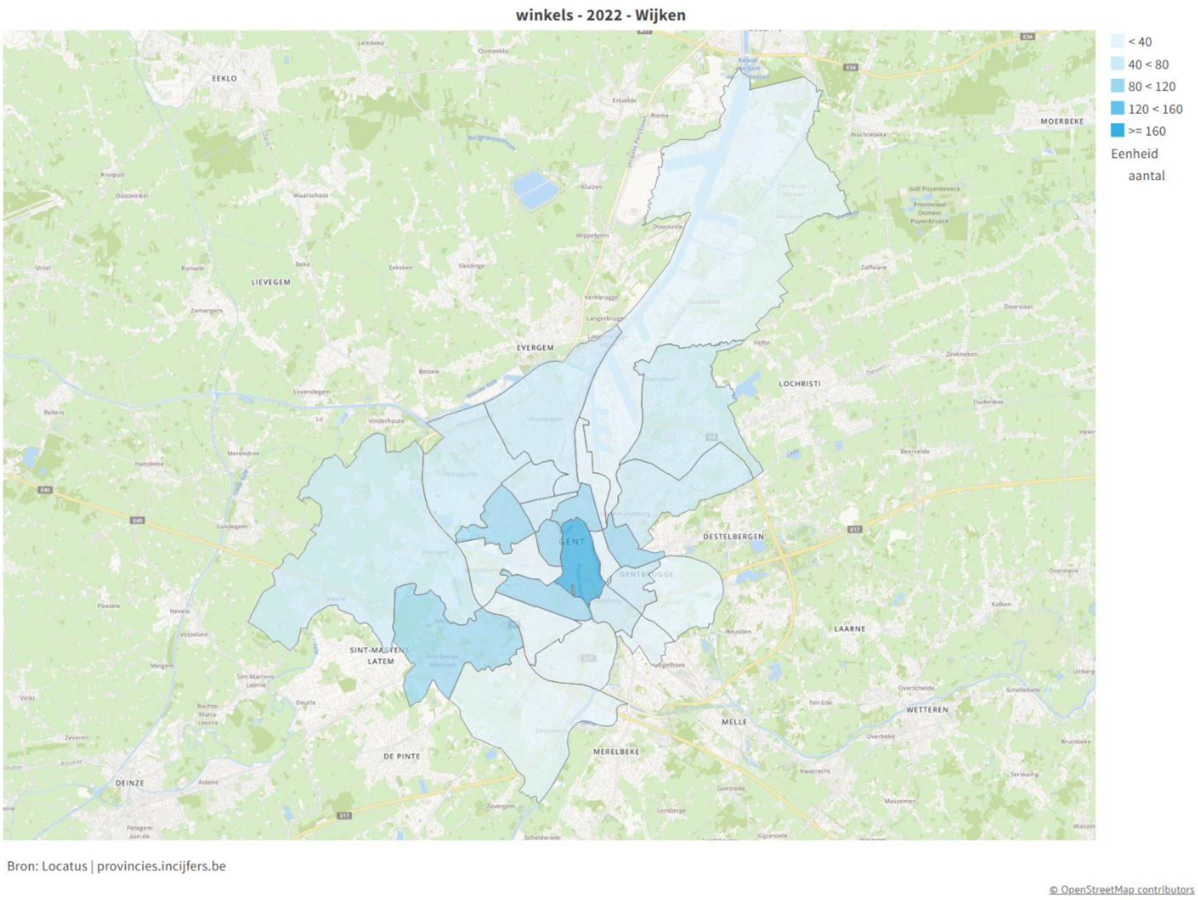
In Table 5.4 the 677 shops have been split into different types and shop floor area

Table 5.4 Type of shops and shop floor area in the district “inner city”

Type of shops	*Number of shops “inner city”*	*Shop floor area “inner city”*	*Number of shops city of Ghent*
Foodstuffs	148	19.115	706
Personal health	52	4.834	191
Clothing and fashion	305	55.738	488
Domestic articles	25	2.556	56
Free time	50	10.214	125
In and around house	42	5.767	216
Brown stuff and kitchen appliances	15	1.245	62
Car and bicycle	8	874	47
Do it yourself	4	2.155	57
Other	28	1.138	88
Total	677	103.636	2.036

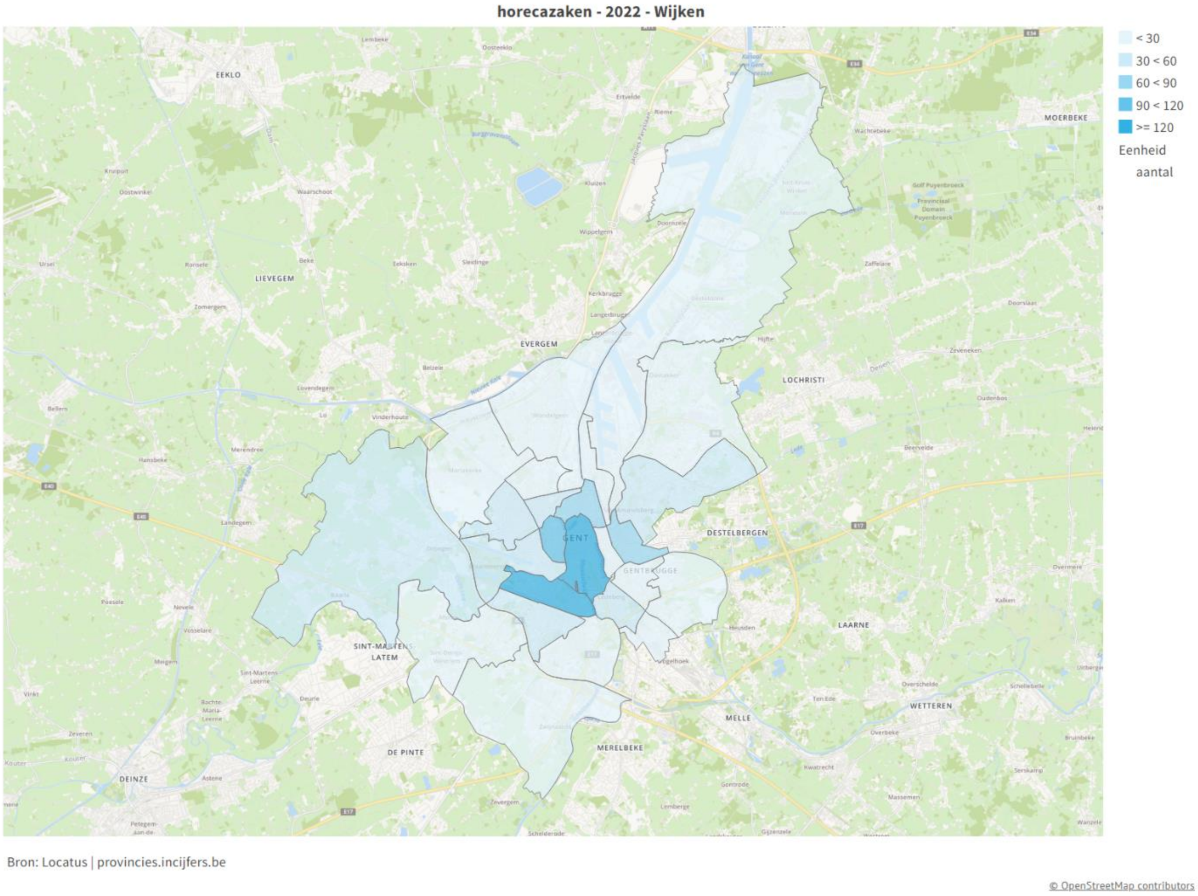
Source: Vlaamse Provincies (2023b) and Gent (2023e)

Figure 5.36: Number of shops per district in Ghent



Source: Gent (2023e)

Figure 5.37: Number of horeca locations per district in Ghent



Source: Gent (2023e)

The 583 horeca locations in the “inner city “ can be split into 14 hotels, 386 restaurants, 26 takeaways, 26 coffee and desert, 119 drinking establishments, 12 other.

In CE Delft (2016), the average number of deliveries per week per selling point has been determined, see table 4.4.

Table 5.5: the average number of deliveries per week per selling point

Tabel 20 Gemiddeld aantal leveringen per week per verkooppunt naar branche in de retail

Branche	Purmerend	Monnicken-dam	Bergen op Zoom	Gemiddeld aantal leveringen per week
Levensmiddelen	10,1	3	16	9,7
Persoonlijke verzorging	2,8	1	9	4,3
Warenhuis	2,5	-	20	11,3
Kleding & mode	4,8	-	4	4,4
Schoenen & lederwaren	5,6	-	4	4,8
Juwelier & optiek	5,6	-	4	4,8
Huishoudelijke & luxe artikelen	4	-	4	4,0
Antiek & kunst	2	2	8	4,0
Sport & spel	4,6	5	4	4,5
Hobby	5,4	30	9	14,8
Media	14	-	9	11,5
Plant & dier	5,6	-	8	6,8
Bruin- & witgoed	8,8	15	8	10,6
Auto & fiets	6	10	8	8,0
Doe-het-zelf	13,5	-	8	10,8
Wonen	3	-	8	5,5
Detailhandel overig	7	1	9	5,7
Horeca (eet)café, restaurant	10,4	-	6	8,2
Horeca overig	5,6	-	6	5,8

Source: CE Delft (2016)

Table 5.6 Estimation of the number of deliveries per type of shop per week in the district "inner city"

Type of shops	*Number of shops "inner city"*	*Average number of deliveriers per week*	*Total number of deliveries per week*
Foodstuffs	148	9,7	1435
Personal health	52	4,3	223
Clothing and fashion	305	4,4	1220
Domestic articles	25	4,0	100
Free time	50	N/A	N/A
In and around house	42	5,5	231
Brown stuff and kitchen appliances	15	10,6	159
Car and bicycle	8	8,0	64
Do it yourself	4	10,8	43
Other	28	5,7	159
Total	677		

Source: Calculations based on Vlaamse Provincies (2023b), Gent (2023e) and CE Delft (2016)

For horeca, the average number of deliveries per week has been estimated on 8,2. Given the 583 horeca locations in the "inner city", this accounts for 4.780 deliveries per week.

5.1.4.3Government buildings

In the LOOP pilot case (year 2020), the city of Ghent and University of Ghent (each having different locations over the city) examined the potential of bundling goods they ordered using a DC outside the city. This might include office equipment, post and parcels, catering, ICT-material, maintenance products and waste. Consolidating (a part) of these flows could be the critical basic volume for the operation of a DC. As such, public instances can give the "good example". This could result in joint purchases and joint sustainable deliveries.

In the pilot project, focus was on the delivery by 3 companies of office equipment and facility material. Material was delivered at a hub of Citydepot in Ghent and the last mile was carried out with electric vans or cargobikes. The pilot resulted in lower kilometers driven in the city and lower CO2-emissions. Consolidation of the goods leads to load factors of vans and cargobikes of 90 – 100%. This is an improvement in comparison with smaller suppliers with a lower filling rate of the van.

A new pilot has been started in 2022. Seven UGENT suppliers will deliver their goods in a city hub. It is expected to reduce CO2 with 60% in the city center and 50% less kilometres with a van in the city center. Current deliveries to UGENT are characterized as dispersed (small shipment loads and parallel deliveries). In the city hub, bundling will take place of several suppliers on 2 fixed delivery days. (Omgeving Vlaanderen, 2022; Universiteit Gent, 2022)

It has been pointed out that an important investment in time and cost is needed for the integration of the data of the different suppliers.

5.1.4.4 Parcel deliveries

For parcel deliveries, calculations have been made inthe R!Sult project for the last-mile delivery to Ghent, investigating whether one or more DC's (North and or South) should be used. Last-mile with a van has been carried out by a neutral stakeholder (consolidating freight flows from different logistics providers). For Ghent, it has been concluded that one DC is the optimal situation for parcel deliveries. (VIL, 2020)

For companies delivering up to 100 parcels per day in Ghent, using a DC is cost saving. For companies with higher volumes the current system used is more cost efficient (thus not using the DC).

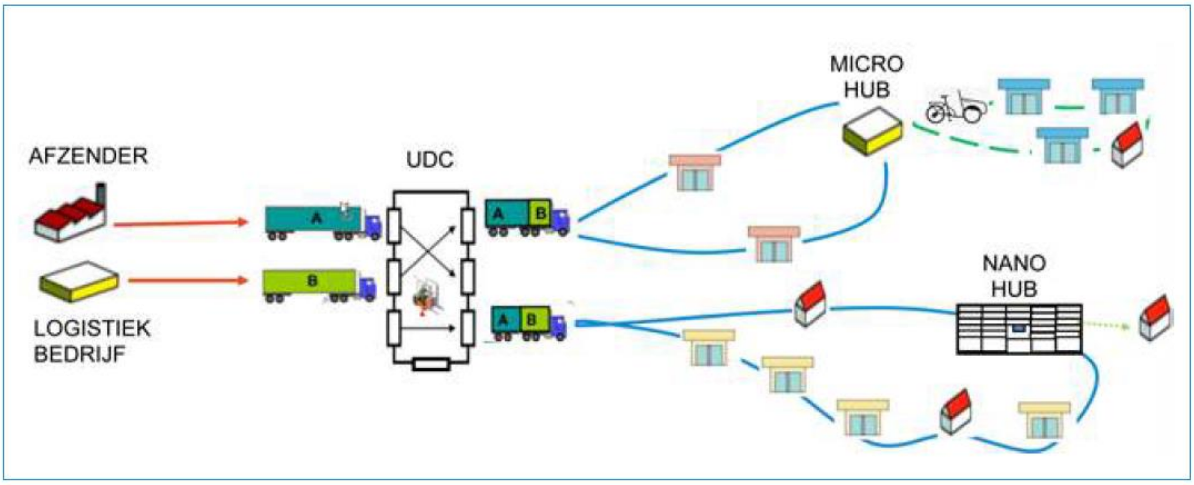
In case of a higher drop ratio (number of parcels per drop), the use of a DC becomes interesting for companies up to 250 parcels per day.

Calculations were based on last mile delivery costs, and do not take into account cost advantages during the line haul (deliver at DC).

It has been advised that cities should take up a supporting role.

In R!SULT (VIL, 2020), the concept of the physical internet has been applied to city freight distribution. Freight flows in and out a city are consolidated via Urban Distribution Centers, microhubs in the city and nanohubs (e.g. lockers, collection points,…). A network of logistic nodes transporting goods in the most efficient ways from origin to destination, implying the need of shared data. City of Ghent was one of the project partners. For parcel deliveries, calculations have been made for the last-mile delivery to Ghent, investigating whether one or more DC's (North and or South) should be used. Last-mile with a van has been carried out by a neutral stakeholder (consolidating freight flows from different logistics providers). For Ghent, it has been concluded that one DC is the optimal situation for parcel deliveries.

Figure 5.38: Overview of transport flows in R!sult-model



Source: VIL (2020a)

5.1.5 Logistics in detail per use case

In the AVATAR-project, 7 potential routes have been identified, of which 4 routes start from a northern DC and 3 routes start from a southern DC. In Figures 5.39 – 5.45, the different routes are presented. For this AVATAR-study, a specific location fort he Northern and Southern DC has been selected: Everstein and Eiland Zwijnaarde.

For the delivery of horeca and retail, we will focus on roundtrips (as shown in routes 1-7) and the potential (un)loading locations. For construction logistics, (un)loading locations are not fixed and will depend on upcoming and will need tailormade solutions. (eg. Test July 2022).

Figure 5.39: Route 1 From Northern DC

	DC1 at the Northern part of Ghent (Everstein)
	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
	Bridges (not in use when red)
	Locks (not in use when red)

Route 1: Start at Northern DC, Kanaal Gent-Terneuzen, Voorhaven, Tolhuisdok, Verbindingskanaal, Coupure, Ketelvaart (until Krook), Ketelvaart (return), De Lieve (until Graslei), De Lieve (return), Coupure, Verbindingskanaal, Tolhuisdok, Kanaal Gent-Terneuzen, Northern DC

Source: Own composition based on Visuris (2023)

Figure 5.40: Route 2 From Northern DC

●	DC1 at the Northern part of Ghent (Everstein)
●	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
)(	Bridges (not in use when red)
≫	Locks (not in use when red)

Route 2 (loop): Start at Northern DC, Kanaal Gent-Terneuzen, Voorhaven, Tolhuisdok, Verbindingskanaal, Coupure, Ketelvaart (until Krook), Ketelvaart (return), De Lieve, Achterdok, Handelsdok, Voorhaven, Kanaal Gent-Terneuzen, Northern DC

Source: Own composition based on Visuris (2023)

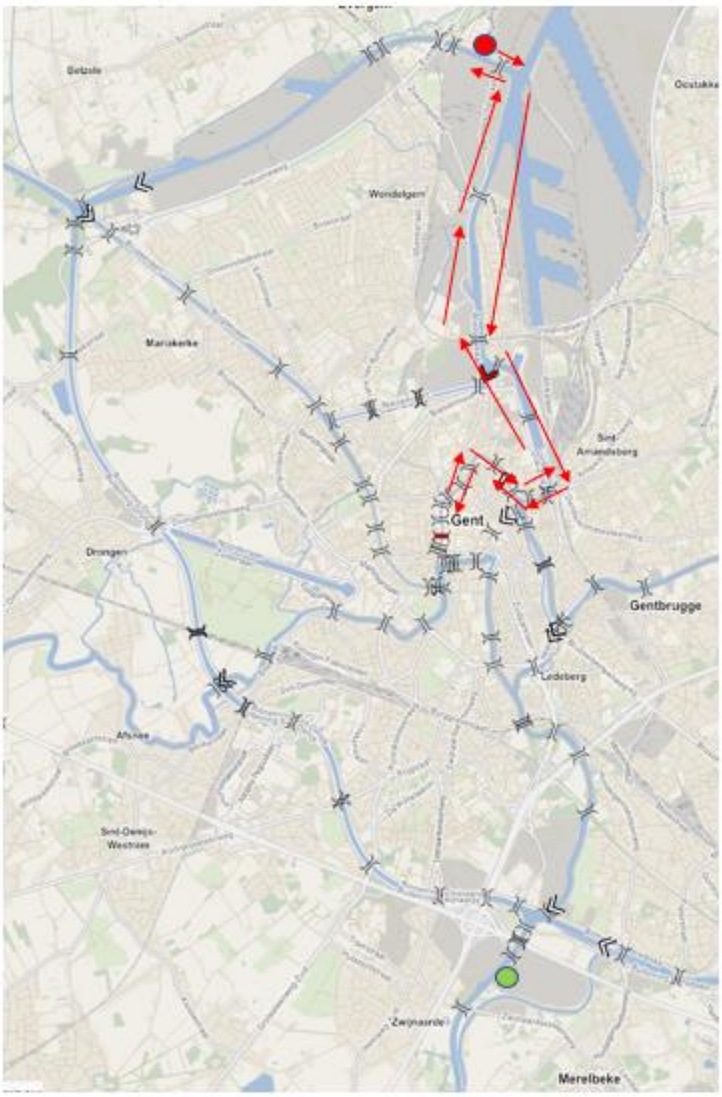
Figure 5.41: Route 3 From Northern DC

●	DC1 at the Northern part of Ghent (Everstein)
●	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
][	Bridges (not in use when red)
»	Locks (not in use when red)

Route 3 (anticlockwise loop; opposite route 2): Start at Northern DC, Kanaal Gent-Terneuzen, Voorhaven, Tolhuisdok, Verbindingskanaal, Coupure, De Lieve, Ketelvaart (until Krook), Ketelvaart (return), De Lieve, Handelsdok, Voorhaven, Kanaal Gent-Terneuzen, Northern DC

Source: Own composition based on Visuris (2023)

Figure 5.42: Route 4 From Northern DC

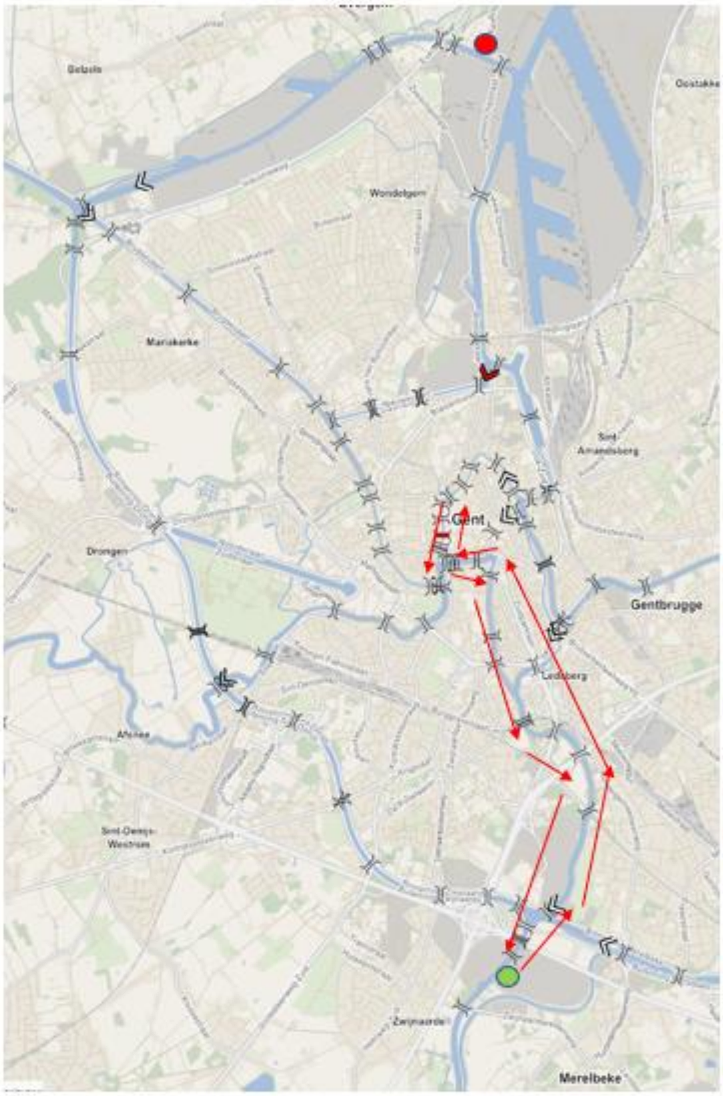


	DC1 at the Northern part of Ghent (Everstein)
	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
][	Bridges (not in use when red)
»	Locks (not in use when red)

Route 4: Start at Northern DC, Kanaal Gent-Terneuzen, Voorhaven, Handelsdok, De Leie (until Graslei), De Leie (return), Handelsdok, Voorhaven, Kanaal Gent-Terneuzen, Northern DC

Source: Own composition based on Visuris (2023)

Figure 5.43: Route 5 From Southern DC

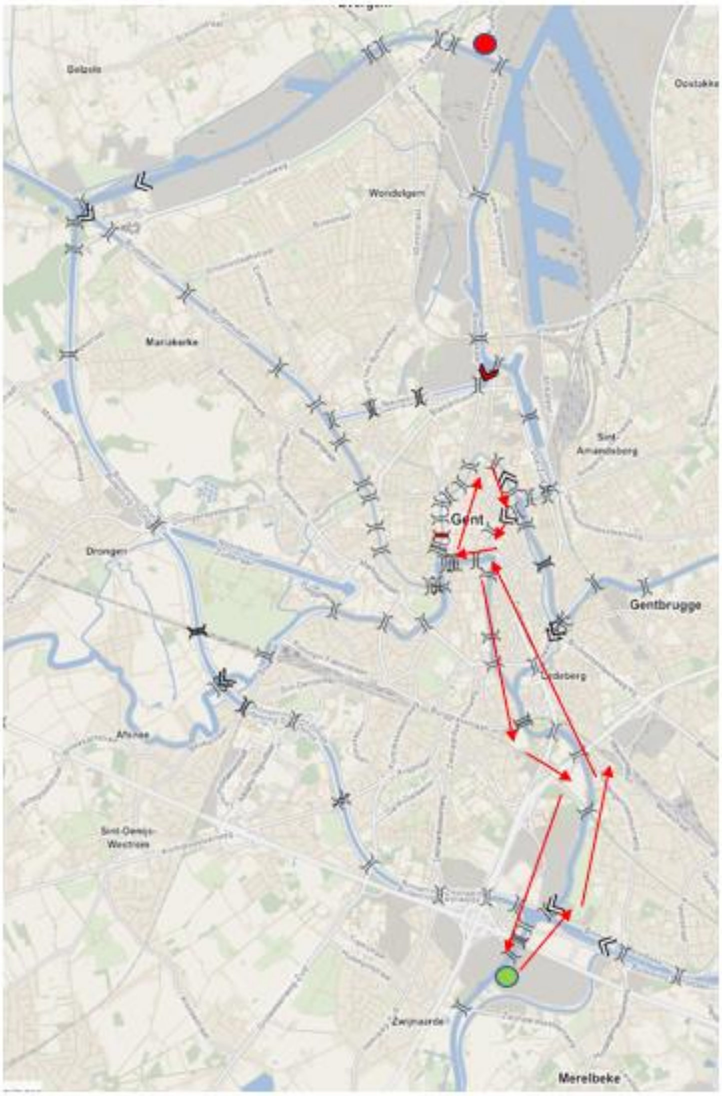


	DC1 at the Northern part of Ghent (Everstein)
	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
][	Bridges (not in use when red)
»	Locks (not in use when red)

Route 5: Start at Southern DC, Muinkschelde, Krook, Ketelvaart, De Leie (until Graslei), De Leie (return), Ketelvaart, Krook, Muinkschelde, Southern DC

Source: Own composition based on Visuris (2023)

Figure 5.44: Route 6 From Southern DC



	DC1 at the Northern part of Ghent (Everstein)
	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
	Bridges (not in use when red)
	Locks (not in use when red)

Route 6: Start at Southern DC, Muinkschelde, Krook, Ketelvaart, De Leie), De Krook, Muinkschelde, Southern DC

Source: Own composition based on Visuris (2023)

Figure 5.45: Route 7 From Southern DC

(red dot)	DC1 at the Northern part of Ghent (Everstein)
(green dot)	DC2 at the Southern part of Ghent (Eiland Zwijnaarde)
)(	Bridges (not in use when red)
»	Locks (not in use when red)

Route 7: Start at Southern DC, Muinkschelde, Krook, Ketelvaart, De Leie), De Krook, Muinkschelde, Southern DC

Source: Own composition based on Visuris (2023)

In the AVATAR-study we focus on palletized goods.

5.2 Hamburg

The objective of this chapter is to give an overview for the selection and determination of the study areas and its characteristics for the two Hamburg Use Cases.

5.2.1 Demarcation of the study area in Hamburg

Hamburg has many different navigable waters that could be considered to be used for waterway transport. Three areas, partly located along or connected to the Elbe River and the port region have been considered for this purpose.

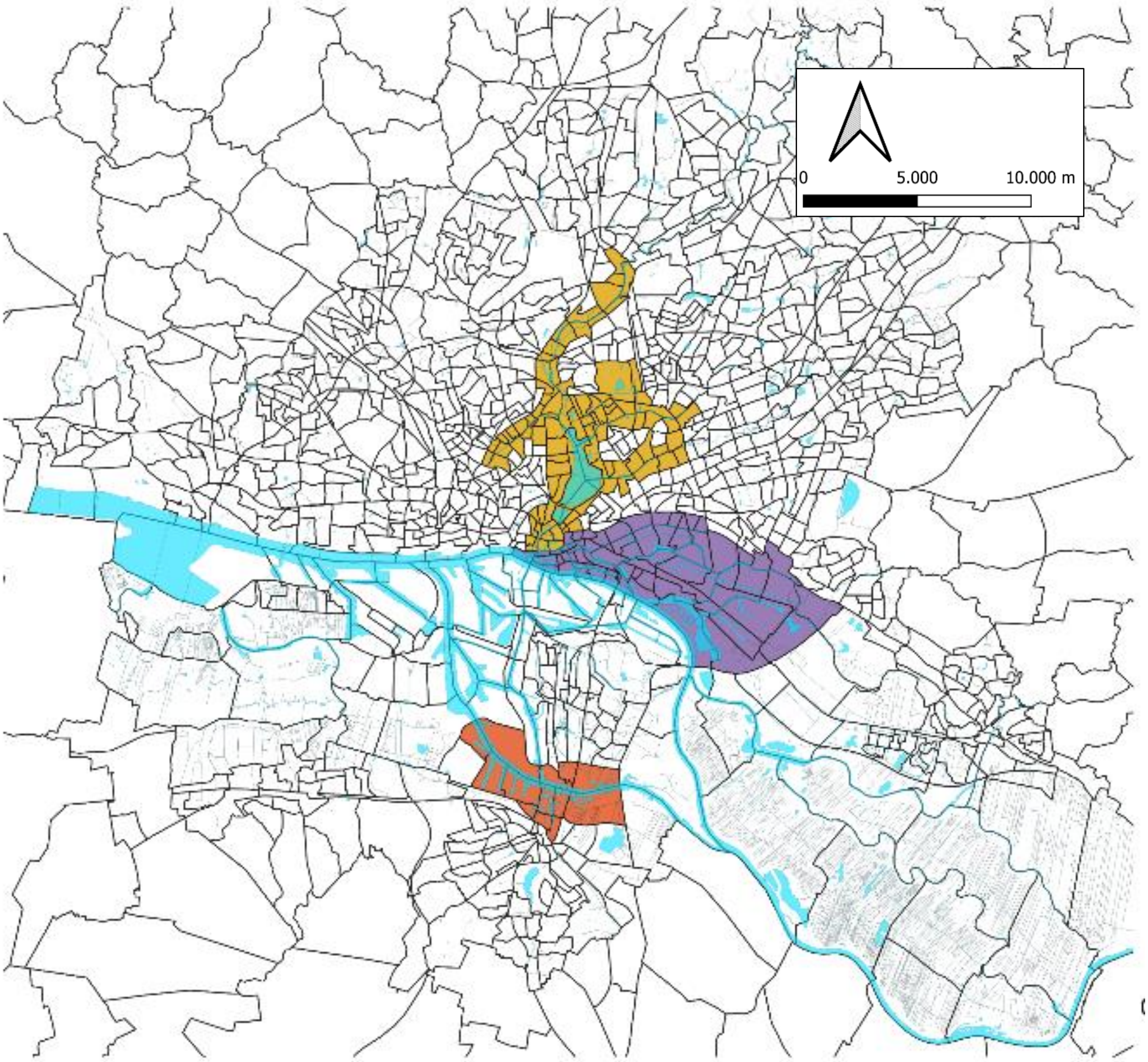


Figure 5.46: Traffic cells of the study areas, based on Fraunhofer CML WaCaBa feasibility study, 2021

The **Alster area** (marked yellow on figure 5.46) stretches as far as the Fuhlsbüttel Lock in the north and is connected to the Elbe via the Alster Lock in the south, which integrates both the Outer Alster and the Inner Alster (green). The urban area around the Alster is primarily characterised by dense residential quarters and the commercial centre and administrative hub of Hamburg's inner city. Although there are, more businesses located here than in the industrial areas accessible by rivers and canals, these businesses consists mainly of service providers, administrations and retailers. What is important to mention, is that, the Alster is also an important natural and recreational area with high traffic from a wide variety of users, such as the historic Alster steamboats, canoes, rowing boats and sailing boats. This conflict of interest with other users on the waterways of the Alster would have made a pilot implementation of an unmanned and autonomous vessel control extremely challenging in this area.

The **Harburg inland port area** (marked red on figure 5.46) in the south of Hamburg is the smallest area and has the lowest modelled commercial goods traffic volumes of the three study areas in comparison. The area is an urban quarter in the process of redevelopment. The orientation of the northern inland port area as a residential and office location results in less freight traffic. The larger part of freight traffic is therefore largely limited to the southern part of the Harburg inland port. Compared to the other two areas considered, the Harburg inland port is much further away from the city centre due to its location in the south, separated by the Elbe. Moreover, interviews did not reveal any real interest on the part of local companies in transport by water.

The **Billbrook & City Süd area** in the east of Hamburg (marked purple on figure 5.46) includes the Bille river and the canals branching off from it in Hammerbrook to City Süd. It consists of the Billbrook commercial and industrial area, a number of commercial and industrial parks in Hammerbrook and the commercial and office location of City-Süd. Moreover, in Hammerbrook and in City-Süd there are also flats. Similar to the Alster area, the freight traffic volumes in the City Süd and Hammerbrook area are dominated by east-west traffic and connections to the motorways. Many CEP (Courier, Express and Parcel Services) companies are based in the Billbrook area in the eastern and southern part and start their delivery tours from there in the direction of Hamburg's city centre.

Due to the various restrictions and competing goals, such as the driving restrictions and recreational uses on the Alster, a use case in this area would not have made sense or would only have been connected with severe restrictions.

The redevelopment of Harburg's inland harbour into more residential and office areas also ensured that there was little interest from local businesses in the area.

The Billbrook & City South area, on the other hand, had more interest from local businesses in transport by water. The proximity to the city and the location of many CEP companies, whose customers and destinations are mostly in the western part of the area, the Hamburg city centre, also argued in favour of carrying out the use case in this study area.

Therefore, the selected most viable use case area, as defined in the WaCaBa Feasibility study has been identified as Billbrook & City Süd (marked purple figure 4.46).

5.2.2 General characteristics of the study area

The Hamburg's total watercourse network comprises flowing waters, canals and lakes (light blue on the figure below). The city of Hamburg consists of 8.1 % water areas, which, with a total area of 755 km², this corresponds to a water area of approximately 9.3 km². Around 2 km² of them are "navigable waters"(dark blue on the figure below)[6]. For the use case of Hamburg, this means that there are many different possibilities for transporting goods on the waterway, the challenge, however, is to identify suitable users and at the same time to find the best solution within the framework of the city's regulations by identifying a good infrastructure for accessing the waterway.

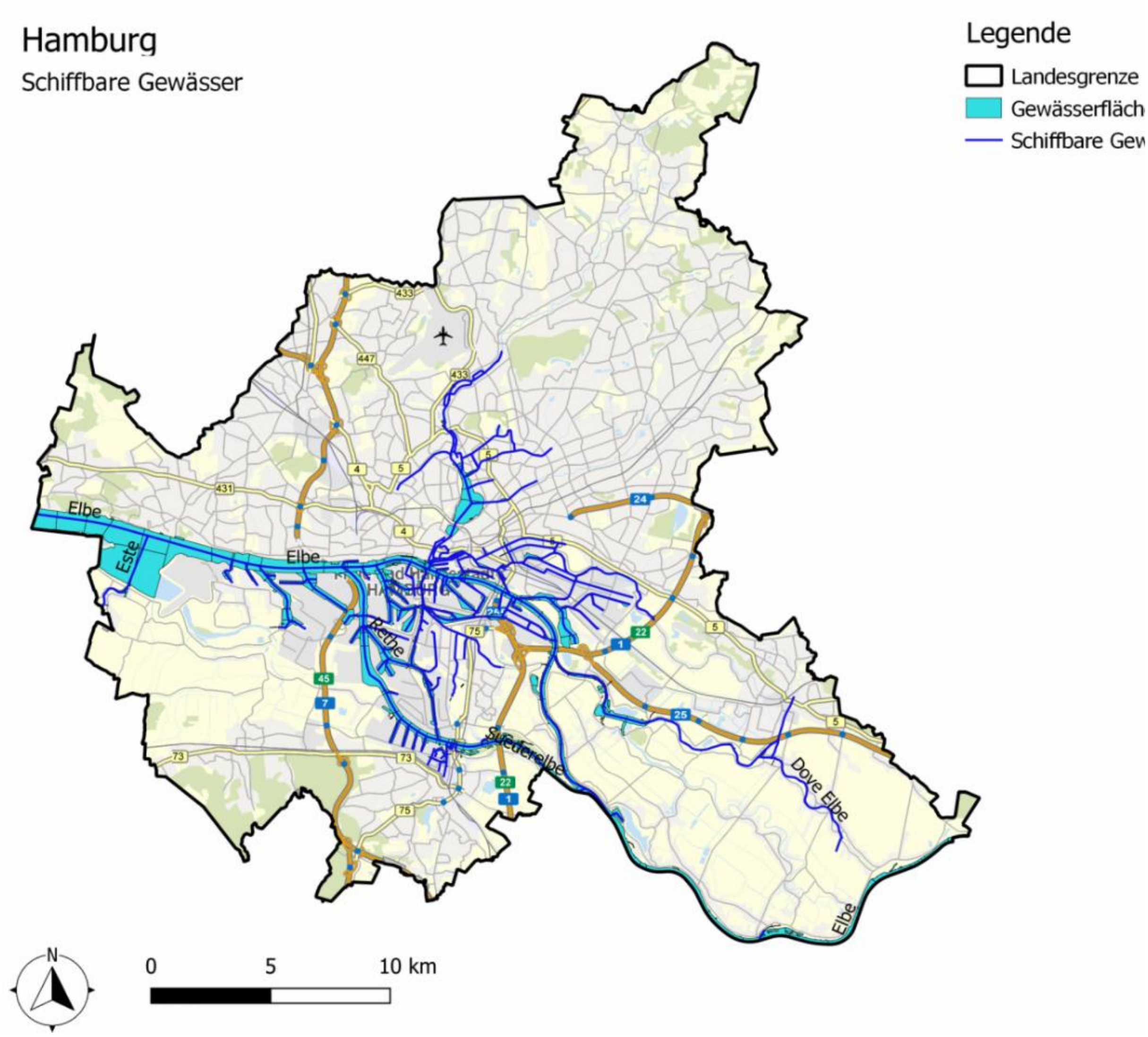


Figure 5.47: Navigable waterways in Hamburg, based on Fraunhofer CML, Feasibility study, 2021

[6] based on Fraunhofer CML, Feasibility study, Hamburg, 2021

In the study area, there are some limiting factors that could pose some challenges to the implementation for a use case. Large parts of Hamburg's waterways are tide-dependent and therefore have varying water levels. The average tidal range in Hamburg is approx. 3.66 m and rises and falls every six hours. The resulting ebb and flood currents reach an average of 2.5 kn. These waters find their limits at locks and barrages. Upstream of these, or in the downstream canals, the water heights are independent of the tide, which means that a constant water level water level and thus constant water depths.

Other limiting factors are bridges, locks and waterway structures. These limit the dimensions of a future cargo vessel. It is assumed that the structures with the lowest clearance heights and widths and with the highest culverts serve as the basis for further considerations within the use case.

The area "Binnen- and Außenalster with Alsterlauf" (marked green figure 5.47) generally has a maximum diving depth of 1.40 m for self-propelled vessels and 1.50 m for towed vessels is required. In the Bille area, the maximum permitted diving depth is 1.80 m and in the Hammerbrook canals it is 1.60 m. In the Harburg area, the maximum permitted diving depth is 1.80 m for self-propelled vessels and 1.50 m for towed vessel.[7]

[7] based on Fraunhofer CML, Feasibility study, Hamburg, 2021

5.2.2.1 Identification of General Freight Transport Flows in the study area

The area of the Bille and its canals is also clearly affected by east-west and north-south freight traffic, which is also concentrated here at the entrances and exits of the motorways and federal roads. The map of this area (see figure 5.48) also shows a significantly higher load along Werner-Siemens-Straße and the Tidekanal bridge (in the middle of the map). Numerous businesses are located along these and their side streets are home to numerous companies that are active in the fields of logistics, building materials, petroleum products, and the construction industry, building materials, petroleum products and the like. They are both as well embedded in the Hamburg traffic model as sources and sinks. However, the high volume of freight traffic along these business locations close to the water suggests that there could be potential for a modal shift to waterways in this area. In total four major CEP service providers (DHL, GLS, Hermes and UPS) have their depots in the Billbrook study area, from where they start their delivery tours in the Hamburg city area.

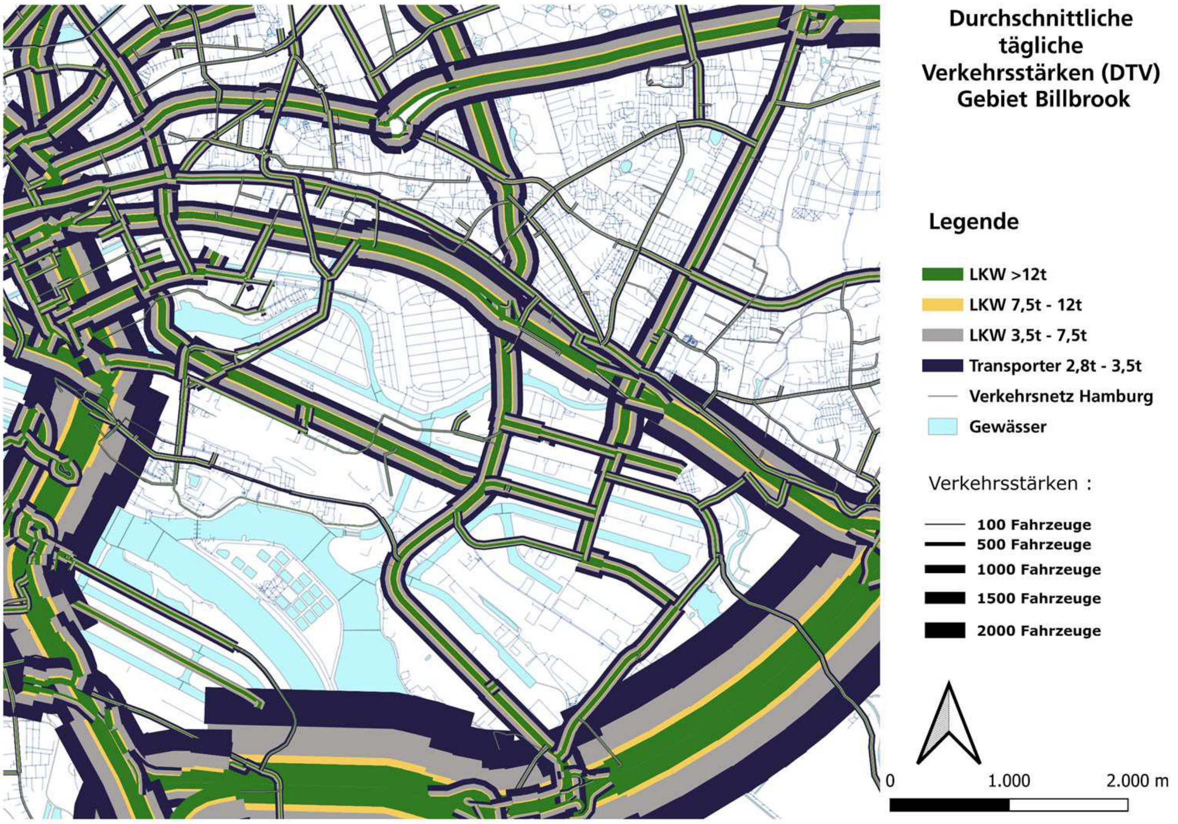


Figure 5.48: Average daily traffic volume by trucks in tons in the Billbrook areas in the year 2018, based on Fraunhofer CML WaCaBa Feasibility study, 2021

5.2.2.2 Infrastructure in the study area

The map marked in red (figure 5.49) shows that the highest density of businesses is in the western part of the study area. This is Hamburg's city centre, where many retailers are located, among other things, as well as offices of service providers. In the eastern part of the area there are many companies with large industrial sites, therefore the density of companies in the area is lower.

Characteristic for the study area is the relatively high number of sources and sinks in the area, moreover the high freight traffic volume of the companies in these areas suggests a potential for shifting traffic to waterways.

The problem of the partly tide-dependent canals in the study area of Billbrook / City Süd, is that navigability is often only possible to a very limited extent due to a lack of maintenance of the waterways. The lack of demand to use the waterway and the resulting lack of maintenance of the waterways often mean that navigability is only possible to a very limited extent. The lack of demand and the resulting lack of maintenance of the waterways and piers in Hammerbrook also resulted that some properties were sold without the embankment to the water as being part of the property. As a result, the businesses located there no longer have access to the water, although they are located on the water.

For the use case selection, all identifiable companies located on or near the waterways were contacted, which either could be considered as shippers or forwarders, or other industries such as gastronomy and the hotel industry. In this study area, this involved about 90 companies. Local companies located on the waterfront or close to it were asked whether the need to shift all or part of their transport volume to the waterway would be a thinkable option. Both partners (DHL and Top-Mehrwert) are located in the study area shown (Figure 5.49).

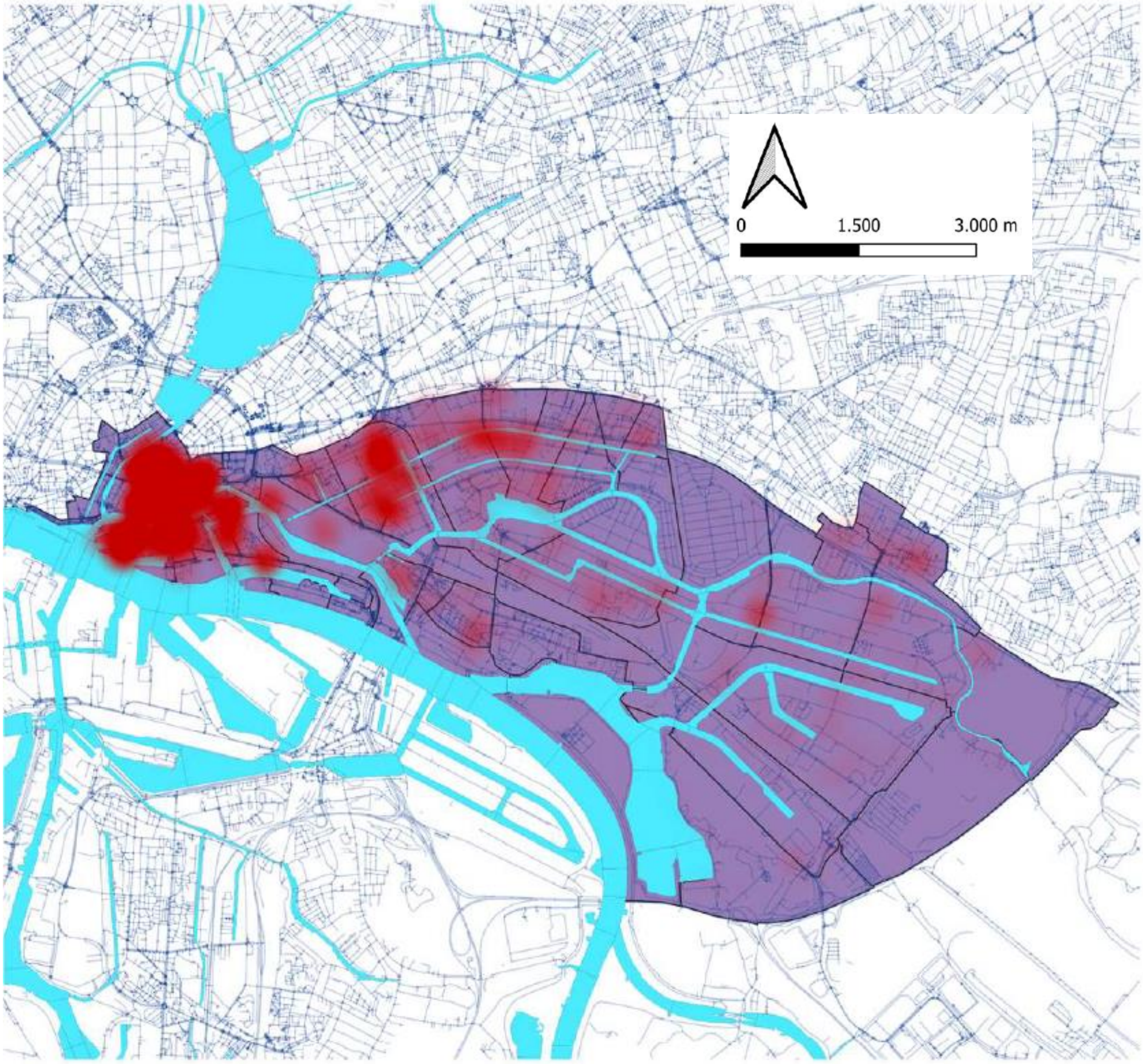


Figure 5.49: Business density in the study area Billbrook, Hammerbrook and City Süd, based on Fraunhofer CML WaCaBa Feasibility Study, 2021

5.2.3 Specific characteristics use cases

***Use case 1**: Parcel delivery*

This figures shows the starting and end point for an operation scenario from the Billbrook area (on the right), near the DHL – Deutsche Post parcel location which runs through the Bille river and its side channels to the end point of Neuer Wall, which is a distance of about ten kilometres by waterway. The street "Neuer Wall" in the city centre is a well-known exclusive and expensive shopping street with a lot of retail shops and offices.

A significantly higher traffic load can be noted along Werner-Siemens-Straße (see right point of the figure 5.50), starting point of a possible pilot boat. Along these streets and their side streets, numerous companies are located that are active in the areas of logistics, building materials, oil products and the like, building materials, petroleum products and the similar industries. They are embedded in the Hamburg traffic model as both source and sinks.

Figure 5.50: Operation Scenario *Use Case 1* - Reference Route “Billbrook channel – Neuer Wall”

Source: Google *Maps*

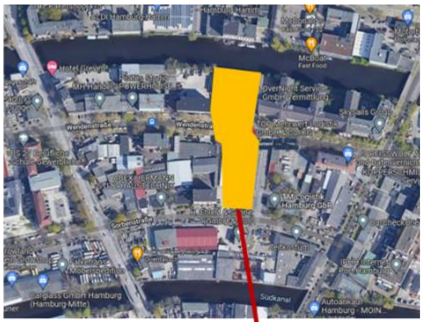
Use case 2: *Retail shuttle*

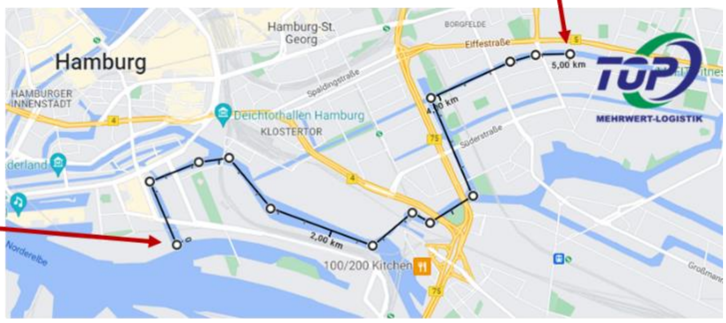
The operation scenario for the second use case in Hamburg is shown on the figure 5.51 below. The starting point for a vessel is on the right side on the map at the TOP Mehrwert-Logistik headquarter and its warehouse which is located in Hammerbrook / Hamm (City Süd) directly at the waterway “Mittelkanal”.

From there on the route towards the new shopping center “Westfield Hamburg Überseequartier” would be approximately (depending on specific route) be five kilometres long. The plan is to develop a pilot concept for the supply of the district with retails and restaurants via an urban consolidation centre (UCC).

The commodities, carried with the barge will mainly be pallets and parcels of all kinds (retail goods from clothing to consumer electronics as well as foodstuffs / fresh products for the restaurants / bars). Currently, the delivery for the shopping centre, hotel, restaurants and the cruise center for the Westfield Hamburg is planned to be carried out by trucks.

Situated in a district in the close neighbourhood of Hamburg's city centre on the Elbe River, which is densely built-up, populated and also popular for tourists, the increased volume of delivery traffic could quickly become a problem. Therefore, competition and prices are currently a bottleneck in the implementation of urban consolidation centre for last mile delivery in Hamburg.





Source: Google Maps

Figure 5.51: Operation Scenario *Use Case 2 – Reference Route: “Mittelkanal – Überseequartier.*

6. Determination of the fleet

In order to determine the characteristics of the fleet, one might start from 2 options. First option is to maximize the capacity (tonnage) of the vessels and determine the position in the city to where can be sailed. By choosing this option, the vessel will be able to transport more tonnage, but the final last mile will be more complicated. Second option is choosing to sail as far as possible in the city centre and determining the dimensions of the vessels to this destination. In AVATAR, focus is on the second option. Goal is to be able to reach the "inner city". As in between solution, one might also opt to start the trajectory with a higher tonnage and higher height. Tonnages will be unloaded during the beginning of the trajectory and the final stage will be perfomed with a lower tonnage and lower height.

Based on research by project partner OHB, choosing the second option has led to a dimension of the vessel of 15 m x 4m without a crane on the vessel. For (un)loading goods, an external crane will be needed. This can be done by a truck with a crane on the quay side.

(to be included: from a city point of view, one might consider to invest in a local truck with crane for (un)loading the vessel)

Figure 6.1 Unloading the urban vessel using a truck with crane.

(c) Sandra Leroy - Unloading the Green Wave in the city of Ghent

In the Interreg North Sea Region #IWTS2.0 project, a first urban vessel for Ghent has been developped and constructed, with the following characteristics: 14.95m x 4 m, 25 tonnage loading capacity, average speed of 10 km/h and full electric propulsion. The vessel is manually controlled.

AVATAR project partners Peter Geirnaert (Urban Waterway Logistics) and Tom Pauwels (POM Oost-Vlaanderen) organized on 6/7/2022 a test run with the urban vessel in Ghent. The Green Wave is the full electric urban vessel (with skipper) developed in the #IWTS2.0 project and has been used as a research vessel in the AVATAR project. See also here.

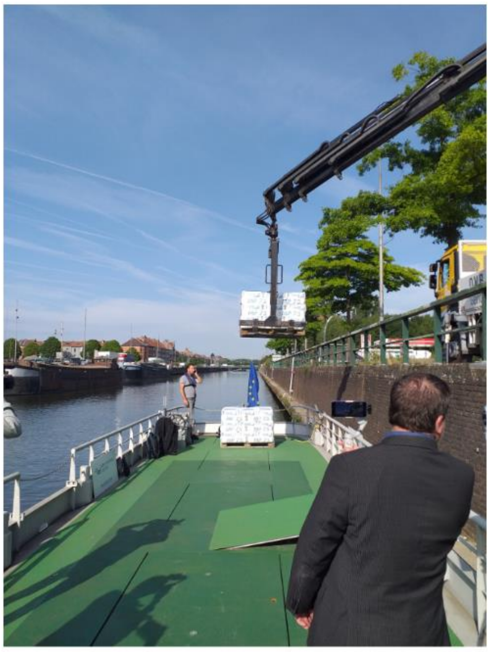
Figure 6.2: Urban vessel for Ghent developped in Interreg North Sea Region #IWTS2.0 project

Source: OHB and UWL

Figure 6.3: Urban vessel for Ghent developped in Interreg North Sea Region #IWTS2.0 project

Source: Informeel magazine: https://northsearegion.eu/avatar/news/avatar-use-case-ghent-in-magazine-informeel-province-of-east-flanders/

Figure 6.4: Loading of the urban vessel in Ghent (6 July 2022)


(c) Tom Pauwels - Loading of the Green Wave

In the AVATAR-project, a new urban vessel has been developped and constructed with the same dimensions but with some technical improvements (e.g. ballast tanks; see here). Additional feature is the possibility to steer the vessel from a distance (semi-autonomous sailing); this is done in cooperation with SEAFAR.

One of the use cases in AVATAR Interreg North Sea Region is focused on city freight distribution vessels sailing during daytime and charging the batteries at night (using a ICE CHP running on hydrogen). While the ICE CHP is charging the vessels, heat is released. In the AVATAR approach, this heat will be stored in a buffer tank that is part of a central heating installation. Project partner E. VAN WINGEN NV takes the lead for this use case. More info about the energy use case is available in a separate document and also here.

The hull of the new vessel arrived in Ghent in January 2022. In a next step, the team of E. Van Wingen co-developped the new AVATAR vessel with the appropriate engine and equipment. SEAFAR was also involved in this development and in the automation part. The universities KULeuven (IMP research group), TUDelft and University of Oldenburg performed tests with the ship in the Living Lab Ghent. SSPA is involved in tracking the performance data. See also here and Figures 6.3-6.4.

Figure 6.5: Arrival of the AVATAR hull in Ghent (January 2022)

© Opleidingscentrum voor Hout en Bouw vzw - Peter Geirnaert

Figure 6.6: Construction of the new AVATAR-vessel

(c) SEAFAR

Palletized materials will be loaded and unloaded with an external crane in case of high quays without transhipment possibilities. In some cases (at some loading/unloading points), dependent on the height of the quay, it will be possible to (un)load the goods using the ramp on the vessel.

The dimensions of the AVATAR-vessel will be the starting point for the chapter on the economic assessment.

On 10 May 2023, the new AVATAR vessel was launched in the water in Ghent.

Figure 6.7 Launch of the AVATAR vessel in the water in Ghent

6.1 Digression on the fleet concept of the WaCaBa, Hamburg

The insights and data related to this subchapter have been elaborated within the WaCaBa (Water Cargo Barge) project and is freely available on the Free and Hanseatic City of Hamburg website.

This chapter aims to describe a possible fleet of vessels that could be used for a waterway transport in Hamburg. The focus here are the results and drafts of the WaCaBa study. The aim is to identify possible parallels and elaborate improvements for the construction of a vessel for the use cases in Ghent where real vessels have been built for (see chapter four and five and first parts of this chapter). What is important to mention is that the vessel shown in the WaCaBa study is only a virtual fleet concept. Compared to the AVATAR project, no ship was built and developed in the WaCaBa project.

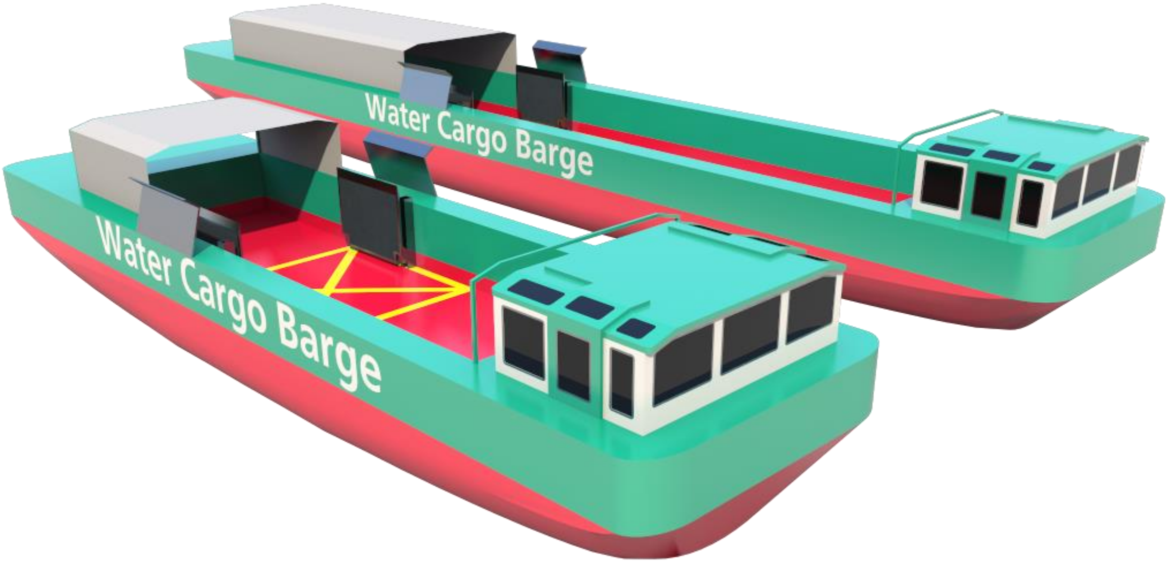


Figure 6.8: Small and Big WaCaBa vessel concept, Based on Fraunhofer CML, WaCaBa feasibility study, 2021

Since at the time of the WaCaBa study it was not possible to identify a concrete framework of needs with firmly involved actors in a supply chain, it was considered useful to propose a vessel that can basically operate in all areas of Hamburg. In the Hamburg use cases of the AVATAR-project this assumption is not useful, because the study area of a potential vessel is limited to the Billbrook district and would not include to pass through the Reesedamm-bridge towards the Inner Alster. This is important to know because the measurements of this bridge were taken to define the height of the vessel.

Two different sizes were planned for the feasibility study: a big and small WaCaBa vessel. The dimensions for the two self-propelled vessels with a planned maximum draft of 1.40 meter are the following[8]:

- **Small WaCaBa:** Length: 18.80 m, width: 5.20 m, height (over waterline): 2.30 m, area: 12.20 x 4 m, Payload weight: 64 tons

- **Big WaCaBa:** Length: 31 m, width: 5.20 m, height: 2.30 m, Loading area: 24.40 x 4 m, Payload weight: 107 tons

Reesedammbridge (Bow view) Reesedammbridge (Loading area section)

Figure 6.9: WaCaBa vessel under the Reesedammbridge, based on Fraunhofer CML, WaCaBa feasibility study, 2021

Handling: The WaCaBa vessel is designed to handle a variety of cargo types, including pallets, rolling units, containers, and skip containers.

[8] Dimension based on: Fraunhofer CML, WaCaBa feasibility study, 2021

Accessibility: The vessel is equipped with a ramp-lift combination, making it easy for cargo to be loaded and unloaded. This feature ensures that cargo can be loaded and unloaded quickly and efficiently, even in difficult conditions.

External Cargo Handling Equipment: The vessel also has the capability to use external cargo handling equipment, such as forklifts, cranes, and other specialized equipment. This allows for even greater flexibility in handling various types of cargo.

Cargo Types:

- Pallets (EPAL): The WaCaBa vessel is equipped to handle standard pallets, including EPAL (European Pallet Association) pallets.
- Rolling Units (e.g. Box pallets): The vessel is also able to handle rolling units, such as box pallets, which are commonly used for CEP (courier, express, and parcel) shipments.
- Container (10-40 feet): The WaCaBa vessel is able to handle standard shipping containers, which come in a variety of sizes including 10-40 feet.
- Skip Containers (Bulk Cargo): The vessel is equipped to handle skip containers, which are commonly used for bulk cargo.
- Cargo Bikes: The WaCaBa vessel can also handle cargo bikes if applicable.

Overall, the WaCaBa vessel is designed to handle a wide variety of cargo types, and is equipped with the necessary features and equipment to ensure that cargo can be loaded and unloaded quickly and efficiently.

A **remote or autonomous** ship operation is technically possible, as all systems necessary for manoeuvring, such as propulsion, can be controlled through IT interfaces. However, navigation and safety monitoring would need to be primarily done through cameras or LIDAR as traditional systems like radar would not be effective in the Hamburg channels. Implementing an autonomous WaCaBa would require a surveillance system that can detect objects, people, animals, and vehicles to avoid collisions and would be technically feasible but would require significant effort. This, combined with the complex structure of traffic participants and their varying levels of awareness, would make autonomous operation of the WaCaBa as a normal equal traffic participant very complex.

For the **type of propulsion** of a WaCaBa vessel, the complex handling of hydrogen and infrastructure requirements compared to a cable connection, it was decided to consider a purely battery-electric drive for the course of the study. A lithium-ion battery certified by a classification society for maritime applications was chosen for battery selection, which can be scaled modularly according to power requirements. According to the study, a WaCaBa takes slightly over an hour to travel a reference distance of 9.5 km, or rounded to 10 km, at a constant speed of 8 km/h. The energy requirements for this travel are as follows: for the larger WaCaBa, 199 kWh and for the smaller WaCaBa, 143 kWh. These energy requirements can be met with the planned battery sizes for both versions of the WaCaBa. However, if the reference distance were to increase to 11 km or more at the same speed, an additional battery pack would be needed for both versions. In general, considering the assumed power curve and the battery used, the larger WaCaBa has a range of 1.58 km per battery pack, while the smaller WaCaBa has a range of 2.20 km per battery pack.[9]

[9] Battery numbers based on: Fraunhofer CML, WaCaBa feasibility study, 2021

The findings and approaches by which the two boats of WaCaBa were developed within the study are important indicators and findings for the AVATAR project, which show the difficulties and challenges in the process of the development of such a project. In particular, the challenge of crossing under bridges, which is determined by the dimensions of the boat, has parallels with the use cases in Ghent, where similar challenges exist. In terms of the vessel's size, for the AVATAR project, it would not make sense to build a 64-ton or 107-ton vessel as conceptually proposed in the WaCaBa study. Particularly in the handling, the partly small channels and deep bridges, and the quantities that will be transported, a ship of this size would only result an additional challenges in the steering. Moreover, it would not even come close to a complete utilisation of the payload. The challenges for the use case of the AVATAR project in Hamburg are mainly due to the partly outdated infrastructure of the waterways and their moorings, as well as legal and insurance-related requirements in relation to the operation of an autonomous vessel fleet. However, this assumption was not calculated or examined in more detail, since as mentioned above, the vessels of the AVATAR fleet (previous subchapter 6.1 to 6.4) were investigated as a primary priority anyway.

7. Energy concept & use case

7.1 Introduction

AVATAR's autonomous zero-emission vessels sailing on green energy will be deployed for inland waterways distribution. In this case, batteries are the power source of the AVATAR vessels. The electrically powered vessels will not run on electricity from nuclear power stations nor on electricity from fossil fuels as that would be contradicting the word 'green energy'.
The AVATAR vessels will run on power from renewable energy sources, generated by large PV (photovoltaic) installations on warehouse rooftops and SME (small and medium-sized enterprise) buildings located along the waterways outside the city center. The problem here is that as the sun does not shine at night, as much solar and wind energy as possible, will be stored in hydrogen at daytime. Therefore, hydrogen becomes the fuel of the AVATAR vessel.

At night, EVW's ICE CHP (= industrial combustion engine for combined heat and power) running on hydrogen converts the hydrogen into electricity that allows the AVATAR vessels to charge their batteries. In other words, EVW's generator on hydrogen (H2 ICE CHP) will produce the needed electricity to charge the batteries of the AVATAR vessels.
While the ICE CHP is charging the vessel, heat is released. This heat will be stored in a buffer tank that is part of the central heating installation of, for example, an SME (= small and medium-sized enterprise). In practice, the heat could also be transferred to the city's district heating network.
The concept of combined heat, power and mobility provides major advantages in terms of energy savings and CO2 emissions. Moreover, the ICE CHP running on hydrogen is 100% emission free. The hydrogen is produced from renewable energy sources as mentioned earlier, therefore 100% green energy is attained. Furthermore, grid congestion can be excluded, because electricity is produced locally, independent of the grid.

E. Van Wingen has expertise of over 40 years in cogeneration solutions (ICE CHP) and energy control systems and almost 10 years in cogeneration solutions (ICE CHP) on hydrogen. This ensures the successful A-Z implementation of the ICE CHP running on hydrogen to charge the batteries of the AVATAR vessels.

7.2 Objectives

The Energy Use Case is focused on the city of Ghent and the objective is to calculate the needed energy (Kilowatt hour electric, kWhe) per day to ensure a given sailing time per day and the required materials it takes to achieve this goal. Moreover, the objective of the Energy Use Case is to also highlight the environmental benefits of deploying the AVATAR vessel in comparison to diesel trucks and the avoidance of grid congestion due to energy being produced locally independent of the grid. The Energy Use Case is an example of how a green and sustainable solution can facilitate the energy transition.

7.3 Methodology

The Energy Use Case is calculated via an Excel-file. Important to mention is that data is filled in in a conservative way to not overestimate the results. More about this will be discussed in the results. Also worth mentioning is that the Energy Use Case is a calculation for deploying one AVATAR vessel which will be a reference point to deploy multiple AVATAR vessels. It should be clear that if decided to deploy multiple vessels, there are economies of scale in place which are also discussed later in the results.

The Energy Use Case calculates the needed energy to charge the batteries of the AVATAR vessel to ensure a given sailing time per day. The batteries will be charged at night as the AVATAR vessel does not sail at night. Furthermore, the batteries of the AVATAR vessel can also be charged during loading/unloading of the cargo. Based on the needed energy per day, a compatible ICE CHP running on hydrogen is selected. Additionally, the Energy Use Case calculates how many kilograms of hydrogen is needed for the H2 ICE CHP to produce the required energy output to eventually being able to charge the batteries of the AVATAR vessel. These calculations serve as input for the actual tests that are performed and vice versa. Based on the energy calculations, a comparison is made in terms of cost per ton between deploying the AVATAR vessel and distribution carried out by two diesel driven trucks of 10 ton.

Another important factor that cannot be neglected are the environmental benefits such as the CO2 reduction that results from the Energy Use Case (which is also calculated and presented) as the AVATAR vessel will run on electricity from a 100% green power source, the H2 ICE CHP. Next to the CO2 reduction, the AVATAR vessel ensures reduced traffic as well as noise reduction in the city. Moreover, safety increases as big diesel trucks are a danger in crowded city environments because of blind spots for example.
Lastly, the importance of producing energy locally and independent of the grid is discussed as the Energy Use Case ensures energy security.

7.4 Results

7.4.1 Production of hydrogen

As described earlier, hydrogen will be the 'fuel' of the AVATAR vessel, meaning that hydrogen will be used in the EVW's hydrogen generator (H2 ICE CHP) that produces energy (kWhe) to eventually charge the batteries of the AVATAR vessel. The hydrogen derives from renewable energy sources such as large PV installations on warehouse rooftops by using the generated energy to produce hydrogen by the use of an electrolyser. The electric consumption of the electrolyser is 240 MWhe (=Megawatt-hour electric). Based on the 240 MWhe electric consumption, there is 144 MWh th (=Megawatt-hour thermal) energy stored in hydrogen. The electrolyser has thus an efficiency rate of 60%. This is an example of how conservative data is entered in the Energy Use Case as there exist electrolysers that have an efficiency rate of +80%.

7.4.2 EVW's Hydrogen Generator running on H2

EVW's 10 kWe hydrogen generator (H2 ICE CHP) consumes 1 kilogram of hydrogen per hour. Based on the energy output of the electrolyser, the EVW's hydrogen generator will run 4.363,63 hours (=144MWh*1000/33(kWh)) per year. This results in 43.636,36 kWhe produced electric energy per year. By producing electric energy, heat is also being produced. The produced heat (at the above given produced electric energy) is 80.000 kWh th per year and this heat can be distributed to the logistic center heating installation and/or to be stored in a buffer tank that is part of the central heating installation (In practice, the heat could also be transferred to the city's district heating network).

7.4.3 Energy savings

Following the produced heat from the H2 ICE CHP, a deeper look is taken into energy savings. First of all the primary fossil energy savings are 100% because the used hydrogen is 100% green hydrogen (hydrogen derived from renewable energy sources). Additionally, there are energy savings in terms of the produced heat of 80.000 kWh th per year from the EVW's hydrogen generator (H2 ICE CHP).
The equivalent of a natural gas heating application that produces 80.000 kWh th per year will cost an SME 17.777,78 EUR in heating. For the natural gas heating application to produce 80.000 kWh th, there is needed 88.888,89 kWh th natural gas as modern heating applications have a return of 90%. Considering that an SME is charged €200/MWh (all-in price), an SME will be charged 17.777,78 EUR per year for the same heat that derives from the H2 ICE CHP. An SME will thus save 17.777,78 EUR per year in heating due to the EVW's hydrogen generator.

Taking into account the 43.636,36 kWhe produced electric energy per year from the EVW's hydrogen generator (H2 ICE CHP), 37.090,91 kWhe can be stored in the batteries of the

AVATAR vessel (taking into consideration a loss – resulting from the energy losses during charging - of 15%) per year.

7.4.4 Energy calculation AVATAR vessel

A diesel driven vessel consumes 5 liters of diesel per hour. The energy stored in 5 liters of diesel is 50 kWh th. Therefore, the equivalent electric consumption of the AVATAR vessel is 12,5 kWhe (50 kWhth/4) for the same trajectory as the return of a diesel engine is only 25%. However, there is a 17% energy loss from the battery to the propeller, so the electric consumption of the AVATAR vessel is 15,06 kWhe.

Given the available 37.090,91 kWhe in the stored batteries per year and the 15,06 kWhe consumption of the AVATAR vessel, the AVATAR vessel is able to sail 2.462,84 hours per year. In other words, if the AVATAR vessel sails 8 hours per day, the AVATAR vessel is able to sail 8 hours per day for 307,85 days per year (2.462,84/8).

To ensure the above sailing time, the EVW's hydrogen generator (H2 ICE CHP) needs to produce 120,48 kWhe (37.090,91kWhe/307,85days) per day, but given that there is a loss of 15%, the H2 ICE CHP needs to produce 141,74 kWhe per day in order to make sure the AVATAR vessel is capable of sailing 8 hours per day for 307,85 days per year. To be able to produce 141,74 kWhe per day, the H2 ICE CHP needs 14,32 kg (141,74kWhe/33kWh/kg/0,3) hydrogen per day or 4.407,71 (14,32kg*307,85days) kg per year. This is the equivalent of 145.454,55 kWh th energy to be stored in hydrogen per year. As a result, 242,42 MWhe green electric energy is produced per year (taking into account 40% energy loss to produce the hydrogen).

If the AVATAR vessel is sailing 8 hours per day for 307,85 days per year, the AVATAR vessel needs to be charged for at least 14 hours (141,74kWhe/10kWe) per day. Important to note is that the time to charge the batteries of the AVATAR vessel depends on the chosen sailing time per day. The above mentioned 8 hours sailing time per day and 14 hours charging time per day serves as a reference point and should be optimized according to the comparison of driving hours with a truck of the same tonnage and destination.

7.4.5 Finance

Before diving into the environmental benefits, a comparison is made in terms of cost per ton between deploying the AVATAR vessel and deploying two diesel driven trucks of 10 ton. The AVATAR vessel has a load capacity of 20 ton, so logically a comparison should be made with a truck of 20 ton. But, for obvious reasons a 20 ton diesel truck driving in the city of Ghent is not realistic, so 2 diesel trucks of 10 ton each are needed. The comparison is made based on a period of 10 years.

There are 2 comparisons in place:

1. AVATAR vessel vs distribution carried out by own 2 diesel trucks of 10 ton
2. AVATAR vessel vs distribution carried out by third parties with 2 diesel trucks of 10 ton

7.4.5.1 Cost of deploying autonomous AVATAR vessel

Period	10 years	
Electrolyser (for hydrolysis)	200.000,00 EUR	
Electricity cost of electrolyser (for hydrolysis)	84.000,00 EUR	=240MWh*€35/MWh*10years
10 kWe H2 ICE CHP	150.000,00 EUR	
Maintenance cost of H2 ICE CHP & Hydrolyser	140.000,00 EUR	4% OPEX per year
Avoided natural gas consumption	- 177.777,78 EUR	=€17.777,78/year*10years
AVATAR vessel	200.000,00 EUR	
Maintenance cost of AVATAR vessel	80.000,00 EUR	4% OPEX per year
Labor cost AVATAR vessel	1.354.560,00 EUR	=(€55/hour*307,85days*8hours*10 years)
Insurance cost of AVATAR vessel	40.000,00 EUR	2% OPEX per year (smart waterway study)
Inspection cost of AVATAR vessel	12.500,00 EUR	1,25K per year (smart waterway study)
Last mile transport	591.960,00 EUR	= (60k elec. Van + 507,96k labor + 24k maint)

Table 7.1: Cost of deploying autonomous AVATAR vessel

First of all there is the cost of the electrolyser (for hydrolysis) which is 200.000,00 EUR. The electricity cost of the electrolyser (for hydrolysis) is 84.000,00 EUR (=240MWh*€35/MWh*10years). Important to mention is that if the price of electricity is higher than €35/MWh, it would be more interesting to sell the electricity to the grid instead of supplying it to the electrolyzer in times of overproduction of green energy (windy and/or sunny weather). Total cost of the hydrogen generator H2 ICE CHP over a period of 10 years is 112.222,22 EUR (=€150.000,00+€140.000,00- €177.777,78). The total cost of the equipped AVATAR vessel is 1.687.060,00 EUR (=€200.00,00+€80.000,00+€1.354.560,00+€40.000,00+€12.500,00) (Shobayo 2020). In this amount is included: the AVATAR vessel, maintenance cost (4% OPEX), labor cost, insurance cost (2% OPEX) and inspection cost. Even though the AVATAR vessel is sailing autonomous, there still has to be someone controlling the AVATAR vessel from a distance via computer. The labor cost is quite high, but this labor cost can be divided over several vessels as one person can easily control multiple vessels from a distance. This is again an example of how conservative data is entered. Lastly, there is the last mile transport. The total cost here is 591.960,00 EUR. The cost of last mile transport consists of a 60.000,00 EUR electrified van, a labor cost of 507.960,00 EUR (=€55/h*3hours*307,85days*10years) and a cost of 24.000,00 EUR (4% OPEX) for maintenance, insurance and other costs. Last mile transport refers to the

goods transported to the end location from the docking point of the AVATAR vessel. Using the electrified van for only 3 hours a day is also a worst case scenario as the van could be implemented to other transportation purposes for the remaining hours of the day.
Adding up all these costs, a total cost of the AVATAR vessel is calculated over a period of 10 years which results to 2.675.242,22 EUR. This comes to a cost of 267.524,22 EUR per year or 869,00 EUR per sailing day taking into consideration the 307,85 sailing days. Eventually a cost per ton is derived from the above calculations. The cost per ton of deploying the AVATAR vessel is 43,45 EUR in the assumption that the AVATAR vessel does 1 roundtrip of 20 tons in 8 hours for 307,85 sailing days per year.

7.4.5.2 Cost of distribution carried out by own 2 diesel driven trucks of 10 ton each

Cost of 1 truck of 10 ton (with a crane) is 200.000,00 EUR, but two are needed so this results in 400.000,00 EUR. The labor costs amount to 1.354.560,00 EUR (= €55/h*307,85days*4hours*10years*2trucks) taking into consideration the two diesel trucks only need 4 hours to complete the trajectory which in practice could be longer as the city of Ghent has a lot of one-way streets and streets that are prohibited for cars and trucks. The diesel cost of these two trucks amount to 728.138,00 EUR (=15l/h*4hours*307,85days*10years*€1,971/l diesel*2trucks) taking into consideration that a diesel truck consumes 15 liters per hour and a cost of diesel of €1,971 per liter which was the price of 27/04/2022. Furthermore there is an insurance cost 40.000,00 EUR (€2.000/year per truck), a road tax of 14.000,00 EUR (€700/year per truck), a maintenance cost of 120.000,00 EUR (€6000/year per truck), an inspection cost of 6.000,00 EUR (€300/year per truck) and other costs of 30.000,00 EUR (€1500/year per truck) that needed to be taken into account (Van Leeuwen, 2017).
In total, the cost of deploying own two diesel driven trucks of 10 ton each is 2.692.697,57 EUR considering 307,85 driving days. This comes to 269.269,76 EUR per year or 874,67 EUR per day. The cost per ton of deploying own 2 diesel driven trucks of 10 ton each is 43,73 EUR in the assumption that the 2 diesel driven trucks do 1 roundtrip of 10 tons each in 4 hours for 307,85 days per year. The 2 diesel driven trucks could be used for the other 4 hours of the day for other transportation uses which indicates again how conservative the data is put in.

7.4.5.3 Cost of distribution carried out by third parties with 2 diesel driven trucks of 10 ton

The total cost over a period of 10 years amounts to 1.970.269,091 EUR (=€80/h*4hours*307,85days*10years*2trucks) considering that the third party also needs 4 hours to complete the trajectory. Additionally, there is a diesel surcharge of 20% that results to 394.053,82 EUR (=€1.970.269,091*0,2). In total, the cost of distribution carried out by third parties with two diesel driven trucks of 10 ton each is 2.364.322,91 EUR taking into consideration 307,85 driving days. This comes to 236.432,29 EUR per year or 768,00 EUR per day. The cost per ton of distribution carried out by third parties with 2 diesel driven trucks of 10 ton is 38,40 EUR.

7.4.6 Environmental benefits

As a last topic, the environmental benefits are calculated when deploying the AVATAR vessel in comparison to two diesel driven trucks of 10 ton. For every liter of diesel, 2640 gram CO2 is released. It is taking into consideration a diesel truck consumes 15 liters diesel per hour and only needs 4 hours per day (compared to 8 hours per day for the AVATAR vessel) to fulfill the trajectory with the same tonnage for 307,85 days per year.
Given the above, the AVATAR vessel ensures 97.528,22 kilograms (2640gr*15l/h*4hours*307,85days/1000*2trucks) CO2 reduction per year which is the equivalent of CO2 absorption of 8,1 hectare (97.528,22kg/1000/12ton) forest surface as 1 hectare can absorb 12 tons of CO2. 8,1 hectare forest surface is then again the equivalent of 12,5 soccer fields (81273,6m^2/6500m^2) as 1 soccer field is 6500m^2.

Also important to mention is that the CO2 reduction that derives from using 100% green energy, green hydrogen in this case, is not calculated in the above CO2 reduction.

7.5 Discussion

The Energy Use Case is an example of how a green and sustainable energy solution is able to ensure 100% emission free production of energy and being able to produce energy locally, independent of the grid at a high return rate. In the end, it is the end result that counts and that determines the impact on climate and our energy bills. That is why it is better to compare the energy performance of total energy solutions, rather than only comparing prices of local produced energy with energy from the grid (which is not green) as it is comparing apples to oranges. Green energy deriving from cities and dependent on the grid will simply not suffice to charge the batteries of the AVATAR vessels as it will lead to net congestion. Cities are not capable of producing sufficient green energy locally as for example wind turbines cannot be

planted in cities. By charging the batteries of the AVATAR vessels via the city grid, it will not guarantee the assurance of energy because on the one hand of net congestion and on the other hand the existing cables are not suited to charge such large energy needs like the batteries of the AVATAR vessels. The existing cables (and the whole electrical infrastructure including transformer cabins, etc.) will have to be enlarged significantly to comply with the needed energy for the AVATAR vessels, e-vehicles, etc. which involves a significant amount of extra costs regarding infrastructures. That is why mentioned earlier, comparing prices of local produced energy independent of the grid with energy from the grid is comparing apples to oranges as it does not showcase the bigger picture which is key here.
We would like refer to the case of 2019 where "Delijn" (public transport by bus) wanted to deploy 20 electrified busses in Ghent, but did not get the licenses from the city of Ghent to install the needed infrastructure at Ghelamco Arena. As a result, Delijn had to cancel the project. Another case is the case of Amsterdam situated in the Netherlands. The grid is unable to cope with the fast growing energy consumption and the transition to green energy that asks for more space on the grid. The grid is overcrowded and companies are asked to find alternative solutions for their energy needs as the grid is not able to meet their energy demands.

As can be seen in the finance section, deploying the AVATAR vessels is more expensive than deploying two diesel driven trucks of 10 ton, but the difference is certainly not night and day, especially if taken into account how conservative the data was put in. More importantly, there should be taken more attention to the environmental benefits the AVATAR vessel ensures such as CO2 reduction, reduced traffic, reduced noise and more safety in the city center. Also, the city of Ghent having a low emission zone and a philosophy of being a green city, only raises the question for how long diesel driven trucks will be allowed in the city centers.

7.6 Conclusion

The Energy Use Case provides energy security and is independent of the grid. Moreover, the produced energy is 100% emission free and thus green energy. This does not only contribute to climate change but will also play a significant role to our energy bills. In current and near future times, energy security is and will be a big topic and total energy solutions that contribute to sustainability in corporate social responsibility will play a key role in the energy transition. Self-suffiency in terms of energy, 0 grams CO2, local employment, avoiding net congestion, sustainable entrepreneurs, less trucks in city centers that result in more safety, reduction of noise and pollution are key factors that will determine the successfulness of the energy transition. E. Van Wingen has been ready for years to facilitate the energy transition and in conjunction with other total green energy solutions (as there is no one right solution), the energy transition could be developed at a higher rate.
The question rather is: is the government ready?

		Unit	Commentary
Production of hydrogen from elctrolysers :			
Electric consumption of elctolyser to produce hydrogen (H2)	240	Mwhe	
H2 produced (energy stored in H2)	144	Mwh th	60% return of electrolyser. (Modern electrolysers have +80% return)
ICE CHP running on H2 from above hydrolyser (*):			
H2 consumption of 10kWe ICE CHP	1	kg/h	
Running hours of H2 ICE CHP per year	4363,6364	h	= 144*1000/33 (33 -> Hydrogen is 33 kWh/kg)
Produced electric energy by H2 ICE CHP / year	43636,36364	kWhe	
Produced heat by H2 ICE CHP / year	80000	kWh th	= 43636,36364/3*5,5 (30% energy 55% heath)
Energy savings :			
Primary energy savings	100	%	Because of 100% green hydrogen
Energy savings from heating application :			
Equivalent nat. gas consumption/burner	88888,88889	kWh th	Modern heating applications have a return of 90%. To produce 8000 kWh th, there is needed 88888,88889 kWh th
Avoided nat. gas consumtion cost (SME price level)	17777,78	€/j	€200/MWh all-in price for a SME (=Small and medium sized enterprises)
Energy savings from transport application :			
Vessels batteries being charged over night by H2 ICE CHP	37090,90909	kWhe	= 43636,3636*0,85 (Energy Stored in batteries, 15% loss)
Profitability highly efficient city distribution vessels at zero g CO2 emission on H2			
Fuel consumption diesel driven vessel	5	L/u	Diesel consumption
Energy in fuel	50	kWh th	there is 10 kWh th stored in 1 liter of diesel, so 5 liters of diesel is 50 kWh th
Equivalent electric consumption e-drive	12,5	kWhe	Return of a diesel engine is in reality 25%, an equivalent e-drive is 4 times as efficient
Electric energy consumption e-drive	15,06024096	kWhe	Battery to propeller, so there is a loss of 17%
Sailing hours (reverse calculation)	2462,836364	s(ail). H.	= 37090,90909/15,06024096
Sailing days	307,8545455	days	= 2462,836364/8 (Sailing 8 hours per year)
kWhe needed per day	120,4819277	kWhe	= 37090,90909/307,8545455 (Needed energy to ensure the above sailing time)
kWhe CHP needed per day	141,7434444	kWhe	= 120,4819277/0,85 (There is 15% loss, so the H2 ICE CHP needs to produce 141,7434444 kWhe)
Kg H2 needed per day	14,3175	kg	= 141,7434444/33/0,3 (Hydrogen is 33 kWh/kg, efficiency of small hydrogen ICE: 30%)
Kg H2 needed per year	4407,713499	kg	= 307,8545455*14,3175
kWh th energy to be stored in H2 per year needed	145454,5455	kWh th	= 4407,713499*33 (H2 is 33 kWh/kg)
MWhe green electric energy per year	242,4242	MWhe	40% energy loss to produce H2

Finance :			
Cost of deploying autonomous AVATAR vessel			
Period	10	years	Calculation based on a period of 10 years
Hydrolyser	200000	€	Cost of the hydrolyser
Electricity cost of Hydrolyser	84000	€	Price electricity €35/MWh : if this price is higher it would be more interesting to sell the electricity to the grid instead of supplying it to the electrolyze in times of overproduction of green energy (windy and/or sunny weather)
H2 ICE CHP	150000	€	Lifespan H2 ICE CHP : 10 years (15kWe H2 ICE CHP will cost 225000)
Maintenance cost H2 ICE CHP	140000	€	4% OPEX per year
- Avoided nat. Gas consumption cost (SME price level) -> e.g. heating of buildings	-177778	€	Avoided gas consumption to heat up buildings for example
H2 consumption in 10 years	43636,36364	kg	
Electric vessel 20T	200000	€	Cost of 20T electric vessel --> 200K for 1x 20T vessel as total investment cost
Maintenance cost Electric vessel 20T	80000	€	4% OPEX per year
Labor cost for the autonomic vessel	1354560	€	Labour cost of 55 EUR per hour and calculated on sailing 8 hours per day for 307,85 days per year for 10 years
Insurance cost of the autonomic vessel	40000	€	2% insurance cost of investment electrical vessel (Smartwaterway study)
Inspection cost	12500	€	1,25K inspection costs per year (Smartwaterway study)
Last mile transport		€	
Electrified Van for last mile transport	60000	€	60K for an electrified Van
Labor cost for Electrified Van	507960	€	Labour cost of 55 EUR per hous and calculated on driving 4 hours per day for 307,85 days per year for 10 years
Maintenance + insurance + other costs electrified Van	24000	€	4% OPEX per year
Total cost of the autonomic vessel over 10 years	€ 2 675 242,22	€	
Total cost of the autonomic vessel per year	€ 267 524,22	€	
Total cost of the autonomic vessel per sailing day	€ 869,00	€	Calculated on 246,2836364 sailing days
Total cost EUR per ton distribution of 20T autonomic vessel	**€ 43,45**	€	

Cost of distribution carried out by own 2 diesel driven trucks of 10 ton each			
Period	10	years	Calculation based on a period of 10 years
2x 10T truck	400000	€	Cost of 1 truck (with a crane): 200.000,00 EUR - Calculated 10 years per truck
Labor cost driver 2x 10T truck	1354560	€	Labour cost of 55 EUR per hour and calculated on driving 4 hours per day for 307,85 days per year for 10 years
Diesel cost of 2x 10T truck	728138	€	Diesel cost of 1,971 EUR / liter - 27/04/2022. Calculated on consuming 15 liters per hour
Insurance of truck over 10 years	40000	€	Insurance cost of 2000 EUR per year
Road tax	14000	€	Road taks of 700 EUR per year
Maintenance cost 2x 10T truck	120000	€	Maintenance cost of 6000 EUR per year.
Inspection cost of 2x 10T truck	6000	€	Inspection cost of 300 EUR per year.
Other costs (Washing of the truck, variable costs,...)	30000	€	Other cost of 1500 EUR per year.
Total cost of distribution carried out by own 10T truck over 10 years	€ 2 692 697,57	€	
Total cost of distribution carried out by own 10T truck per year	€ 269 269,76	€	
Total cost of distribution carried out by own 10T truck per driving day	€ 874,67	€	Calculated on 307,85 driving days
Total cost EUR per ton distribution carried out by own 20T truck	**€ 43,73**	**€**	
Cost of distribution carried out by third parties with 2 diesel driven trucks of 10 ton			
Period	10	years	Calculation based on a period of 10 years
Cost over a period of 10 years	1970269,091	€	Cost of 80 EUR per hour and calculated on driving 6 hours per day for 307,85 days per year for 10 years
Diesel surharge	394053,82	€	20% diesel surcharge
Total cost of distribution carried out by third parties with 2x 10T truck over 10 years	€ 2 364 322,91	€	
Total cost of distribution carried out by third parties with 2x 10T truck per year	€ 236 432,29	€	
Total cost of distribution carried out by third parties with 2x 10T truck per driving day	€ 768,00	€	Calculated on 307,85 driving days
Total cost EUR per ton distribution carried out by third parties with 20T truck	**€ 38,40**	**€**	
Environmental benefits			
Gram CO2 per liter diesel	2640	gr	
Diesel consumption of truck per hour	15	l/h	
Ton CO2 per hectare	12	ton	
kg CO2 reduction /year	97528,32	kg	
CO2 equivallent forest surface	8,12736	ha	
	81273,6	m²	1 football field is 6500 m²
Short summary			Highly efficient city distribution vessels at zero g CO2 emissions on H2 ensure 97.528,22 kg CO2 reduction per year. This is the equivalent of CO2 absorption of 6,09 hectare forest surface. 8,13 hectare forest surface is than again the equivalent of 12,5soccer fields.

8. Economic assessment for selected use case

This activity consists of the elaboration of a business case (and financial plan) focussing on the necessary conditions that should be fulfilled to make city distribution with an (highly) autonomous vessel economically interesting for private actors. This will include (among others) the estimation of challenges, risks, investments (CAPEX), urban IWT incentives and operating costs (OPEX).

8.1 Ghent

In order to be able to assess use cases for the City of Ghent, an Excel cost calculation tool has been worked out. An Excel-tool is being constructed for the calculation of the cost of using a fleet of (highly) autonomous vessels in the City of Ghent. Main goal is to calculate a cost per transported unit (e.g. a cost per transported pallet).

In general, a distinction can be made between:

- ⇨ Cost of the hull (=Cost 1)
- ⇨ Cost of equipment needed for “traditional” sailing (=Cost 2)
- ⇨ Cost of equipment (automation cost) needed for “sailing from a distance” (=Cost 3)

The calculation tool makes it possible to take into account the effects of a different location of a distribution hub at the border of the city (e.g. at the Northern or Southern part of Ghent).

In the calculation tool, the following investment costs (CAPEX) are taken into consideration:

- ⇨ Cost of the hull (incl. engineering costs);
- ⇨ Cost of the equipment needed for “traditional sailing”;
- ⇨ Cost of the equipment (automation costs) for “sailing from a distance”;
- ⇨ Infrastructure costs along the trajectory;
- ⇨ Residual values.

Besides the CAPEX-costs, it is also necessary to include different operational costs (OPEX), such as:

- ⇨ Cost of energy;
- ⇨ Revenues;
- ⇨ Financial loan;
- ⇨ Maintenance costs;
- ⇨ Insurance costs;
- ⇨ Waterway permit;
- ⇨ Salary skipper and skipper vessel ratio (this refers to the number of skippers that can be replaced by 1 remotely sailing skipper);
- ⇨ Inspection costs.

Different constraints (affecting the cost calculation) are taken into account:

- Vessel characteristics: e.g. dimension, payload capacity, energy consumption, lifespan;
- Operational characteristics: e.g. operational time, number of outgoing and incoming flows, electricity consumption;
- Characteristics of the trajectory: e.g. speed, number of stops, loading/unloading time, locks, number of roundtrips, charging time,…
- Characteristics of the infrastructure: e.g. bridges, locks,…

8.2 Hamburg

The following chapter focuses on the economic assessment which is related to the Hamburg Use Cases. The facts of this subchapter also go hand in hand with the descriptions of chapter 6 “Determination of the fleet” and chapter 4 “Use case selection”, which deal with the use case selection in Hamburg and the urban vessel concept of the Water Cargo Barge (WaCaBa) Feasibility study[10].

The use of electric motors for transport in general is becoming increasingly popular, and the city of Hamburg in Germany is no exception. The electric CO2 free transport along urban waterways is the next towards CO2-free transport in cities. With its extensive network of canals and waterways, Hamburg is well suited for water transport. The use of electric vessels could offer a number of economic benefits, but there are also challenges, which could lead to the implementation and interest of potential stakeholders being questioned and stalled.

An economic assessment of electric vessel transport in Hamburg would need to consider a range of factors, including the cost of the vessels themselves, as well as ongoing operating costs such as fuel and maintenance. It would also need to take into account the potential revenue generated by transporting goods and people along the city's waterways.

However, the conditions and assumptions from chapter 4 "Use Case Selection", chapter 6 "Determination of the fleet" as well as the findings from the Energy Use Case must also be taken into account when it comes to the economical application. Together with the experience in the development of electric propulsion and construction of a ship from the project partners in Ghent (EVW and OHB), important aspects can thus be taken into account in the economic assessment for Hamburg use cases.

The points for capital expenditures and operating costs in this part are based on assumptions that go alongside with the WaCaBa study in Hamburg. They can be helpful for the development of use cases for economic feasibility in Hamburg.

[10] Fraunhofer CML, WaCaBa feasibility study, 2021

Consideration of operating costs (OPEX)

For the calculation of operating costs, the following categories can be considered[11]:

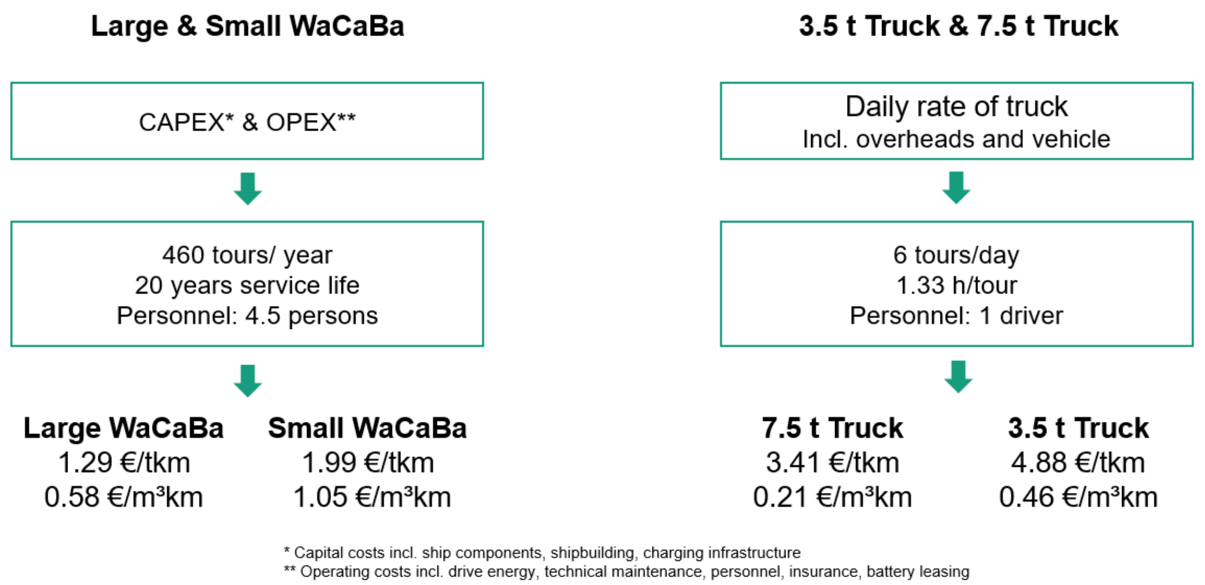
- energy consumption (kWh/km)
- maintenance (Vehicles, transshipment yards and equipment)
- personnel (Ship management, charging operations, Handling, logistical activities and control)
- insurance and general management and administration
- battery leasing (depending on the size and range of the vessel)

Consideration of capital expenditures (CAPEX)

For the calculation of capital expenditures, the following categories need be considered[12]:

- Costs of the ship components
- Construction of the transshipment yards and purchase of the transshipment equipment
- Planning and implementation of shipbuilding
- Loading infrastructure

Figure 8.1 – CAPEX & OPEX of WaCaBa (Water Cargo Barge) 460 trips per year compared to Truck



Source: Fraunhofer CML, WaCaBa feasibility study, 2021

Based on the calculation of the Fraunhofer CML, a trip of the large WaCaBa has to be sold for 1045 € or a trip of the small WaCaBa for 956 € per day if 460 trips are made per year. To reflect fluctuations in WaCaBa utilization, an average utilization of 75% of the maximum load

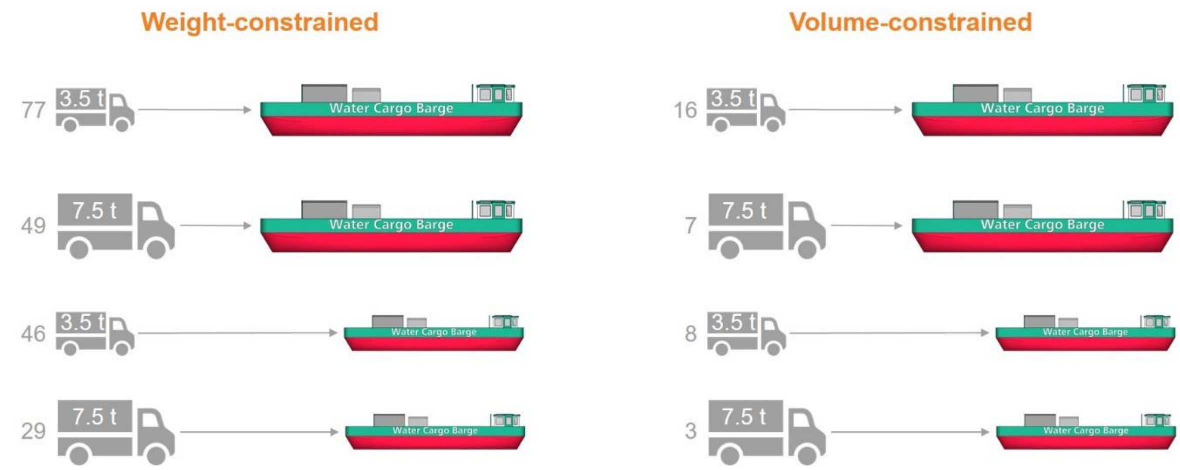
[11] Categories for operating costs based on: Fraunhofer CML, WaCaBa feasibility study, 2021

[12] Categories for capital expenditures based on: Fraunhofer CML, WaCaBa feasibility study, 2021

in tons or cubic meters is assumed. This allows the calculation of the price in euros per tonne-kilometre or euros per cubic meter-kilometer, which is comparable with other transport modes. An overview of the calculated key figures can be found in figure 8.1 above. Even in comparison to an operating profile with 460 WaCaBa journeys per year, the trucks for inner-city transports currently have a cost advantage. An exception would be the transport of heavy goods in large quantities. The WaCaBa vessel would make it possible to transport a larger quantity in a shorter time at a lower price per ton. The competitive situation would improve with better capacity utilization, night operation and further densification of use, or a pricing of the external effects of HGVs (CO2 levies, city tolls).[13]

The figure 8.2 below therefore shows in particular that volume and weight-dependent goods have an advantage over voluminous goods, as considerably more truck trips can be saved in comparison. In particular, the smaller of the two vessels developed in the WaCaBa study have a greater advantage here in relation to the volume constrained consideration than the larger vessel. For this instance, it is important to consider more weight-dependent goods when it comes to the economic assessment of such a related project.

Figure 8.2 - Reduction of truck deployments per tour



Source: Fraunhofer CML, WaCaBa feasibility study, 2021, Final presentation for AVATAR conference in Hamburg

Although, there are also some potential challenges to consider when it comes to electric vessel transport in Hamburg. For example, the upfront cost of purchasing electric vessels may be higher than traditional diesel-powered boats, which could be a barrier to entry for some operators. Additionally, the infrastructure required to support electric vessels, such as charging points and maintenance facilities, may not be fully developed in all areas of the city.

The use of autonomous vessels can also reduce labor costs, as the vessels can operate without the need for a crew. While this may result in job losses for crew members, it could also create new jobs in the development, the monitoring in a control center and maintenance of autonomous vessels.

[13] Fraunhofer CML, WaCaBa feasibility study, 2021, p. 78

Despite these challenges, the economic assessment of electric vessel transport in Hamburg suggests that the benefits could outweigh the costs in the long term. By reducing operating costs, improving environmental performance, and potentially generating new revenue streams, electric vessels could offer a sustainable and efficient transport solution for the city's waterways.

To encourage this shift, the city needs to implement a range of initiatives to support businesses and individuals who wish to use water transport. These include subsidies for the purchase or rental of boats and barges, as well as funding for the construction of loading docks and other infrastructure to facilitate water transport. In addition, the city needs to work with shipping companies to improve the reliability and speed of water transport services, making it a more attractive option for those looking to transport goods. This includes investing in modern vessels and technologies to ensure that shipping is both safe and efficient.

To achieve these goals, it is also important to adapt the policy related framework regarding the last mile strategy of the city. Overall, these measures can help to create a more supportive environment for water transport on the last mile. By providing funding, regulatory support, and safety standards, the city needs to make it easier for businesses to adopt this mode of transportation, which has the potential to reduce traffic congestion and improve the environment. To find more policy-related insights, please have a look at the Policy Position Paper[14] in chapter 11, which has been elaborated within work package four of the AVATAR project and has also been published on the AVATAR project website.

[14] INTERREG North Sea Region Project AVATAR, Policy Position Paper, 2023

9. Socio-economic and environmental effects

9.1 Ghent

9.1.1 Energy Use Case

The Energy Use Case is a green and sustainable solution that guarantees 100% emission free production of energy, produced locally and independent of the grid. Energy security is a big topic as of late and will only grow in importance. The Energy Use Case provides energy security whilst supplying 100% emission free!

The EVW's hydrogen generator produces 80.000 (kWh th) in heat which can be a used in the central heating installation of an SME or the heat could also be transferred to the city's district heating network. This heat is not only produced emission-free, it also saves you 17.778,00 EUR per year if you make use of your standard gas heating application.

Did you know that one autonomous AVATAR vessel of 20 ton ensures a CO2 reduction of 97.528 kilograms per year compared to 2 diesel trucks of 10 ton ? This is the equivalent of CO2 absorption of 8,13 hectare forest surface. 8,13 hectare forest surface is than again the equivalent of 12,5 soccer fields. Imagine what a fleet of autonomous AVATAR vessels can do!

9.1.2 AVATAR VESSEL

The benefits of implementing the AVATAR vessels go beyond the significant CO2 reduction, it also leads to reduced traffic, reduced noise and more safety in the city center.

Did you know that the AVATAR vessel is made out of aluminum and has a length of 15 meters and is equipped with 5 camera's, 2 GPS antenna, 2 4G antenna and 1 LIDAR ? This ensures the safety of deploying the autonomous AVATAR vessel in open water.

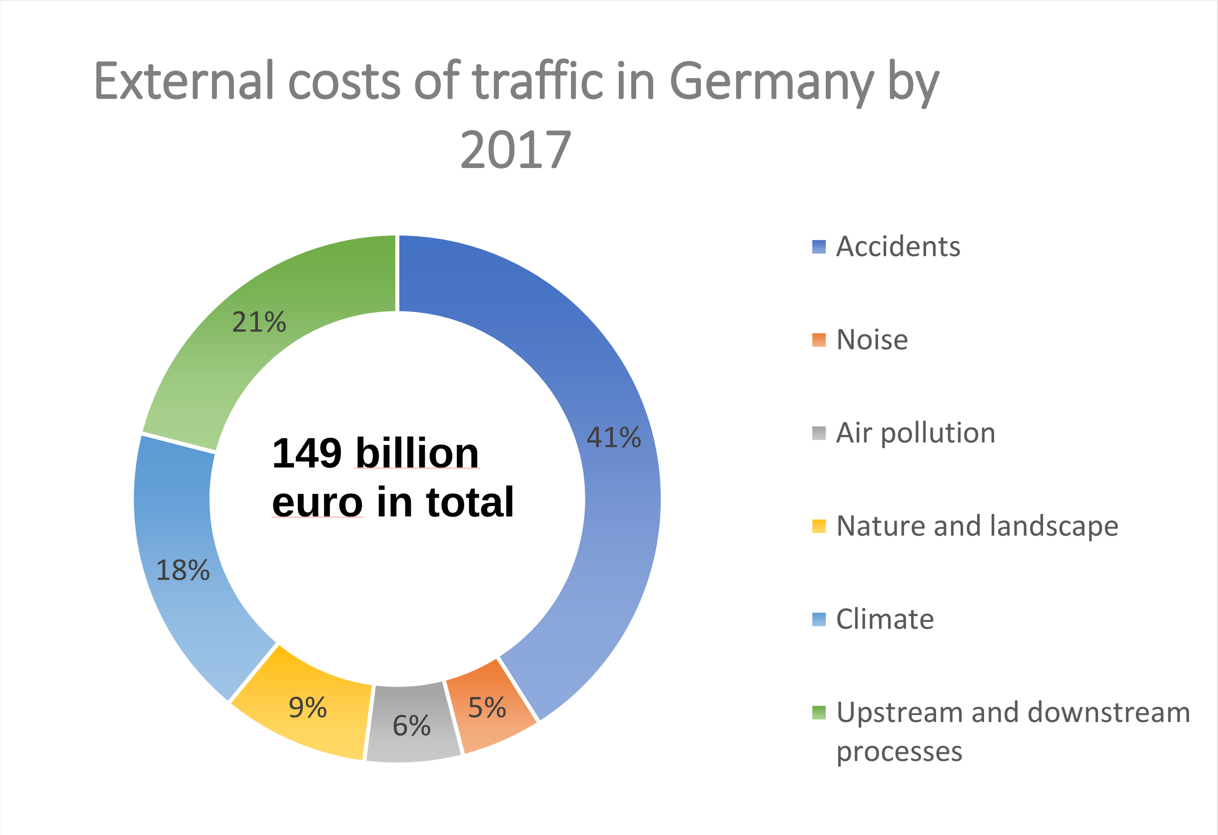
The AVATAR vessel is able to sail 8 hours at a speed of 8 km/h with the current battery capacity of +/- 85 kWh. Charging the AVATAR takes 13 hours if the battery is completely empty, which will usually not be the case. Important to consider is that there is room for improvement to improve the speed, the battery capacity and the charging time.

9.2 Hamburg

As described in the previous chapter, shifting transport from truck to rail could not only lead to economic benefits, but also helps support to socio-economic and environmental effects in a positive way. This chapter explains in more detail the socio-economic and environmental advantages for the city of Hamburg of shifting towards zero emission transport by boat. A special point here are the external costs that made up 149 billion euros in total for traffic in Germany in 2017 (see figure 9.1 below).

External costs refer to the societal and environmental costs associated with an economic activity that are not borne directly by the producers or consumers involved. In the case of traffic, these costs can include various negative impacts on society and the environment. However, the external costs have not decreased, but rather increased. This is because savings from technological progress are nullified by more and heavier traffic. On the other hand, reducing traffic often conflicts with society's need for mobility[15].

Figure 9.1: External costs of traffic in Germany by 2017



Source: based on Allianz pro Schiene | 08/2019 | on the basis of Infras

Here are some insights into the external costs and the effects that are caused mentioned in the figure 9.1:

Traffic **accidents** result in significant costs, including medical expenses, property damage, loss of productivity, emergency response, and legal proceedings. Traffic **noise pollution** can lead to health issues such as stress, sleep disturbance, and cardiovascular problems. It also affects the quality of life for individuals living near busy roads. Vehicle emissions contribute to air pollution, leading to respiratory problems, cardiovascular diseases, and environmental

[15] based on Allianz pro Schiene, external costs, 2017

damage. The costs associated with **air pollution** here include healthcare expenses, reduced crop yields, and damage to ecosystems.

Nature and Landscape: Traffic infrastructure can have negative impacts on natural habitats, biodiversity, and landscapes. These costs can include the loss of wildlife habitats, fragmentation of ecosystems, and degradation of scenic beauty.

Climate: Transportation is a significant contributor to greenhouse gas emissions, primarily through the burning of fossil fuels. The resulting climate change can lead to various costs, including extreme weather events, sea-level rise, and impacts on agriculture and infrastructure.

Upstream and Downstream Processes: These costs refer to the environmental and social impacts associated with the entire life cycle of a vehicle, including the production, use, and disposal stages. They can include energy consumption, raw material extraction, waste generation, and social issues related to manufacturing and recycling processes.

By introducing an electric zero-emission vessel in urban transport, several positive socio-economic and environmental effects can occur. Some of the key benefits, which also influence the external effects described above, are:

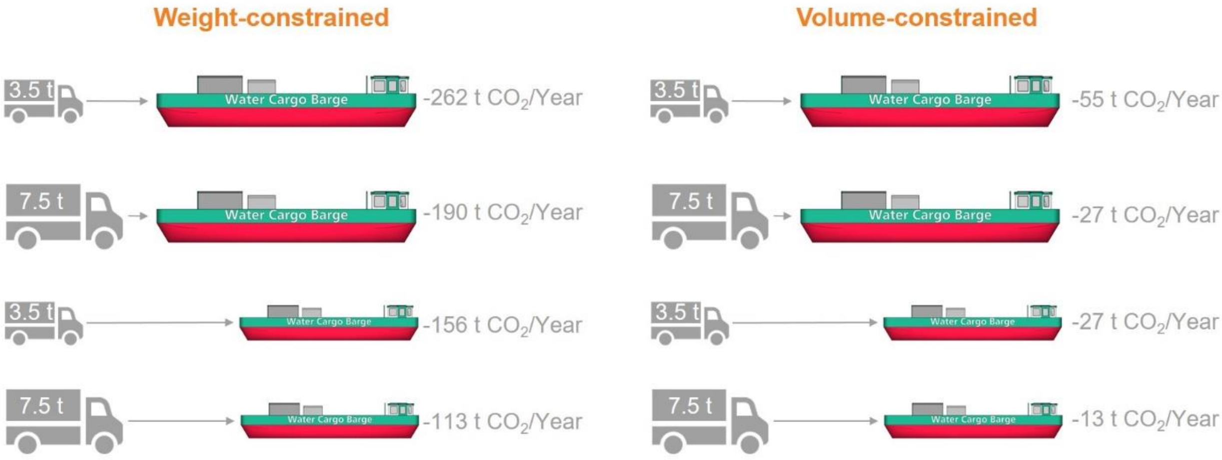
- **Reduced Air Pollution**: Electric ships are powered by electricity, which produces zero direct emissions during operation. In contrast, trucks typically run on diesel or gasoline, emitting pollutants such as nitrogen oxides, particulate matter, and carbon dioxide. By utilizing electric ships for urban transport, air quality in cities can be improved, leading to better public health outcomes
- **Noise Reduction:** Electric ships are much quieter than traditional ships powered by internal combustion engines. This reduction in noise pollution can significantly improve the quality of life for urban residents, especially those living near waterfronts or busy harbor areas. In particular, the noise reduction caused by traditional diesel trucks that otherwise have to drive through the already congested city is significantly reduced by the transport with an electric ship. It also enhances the tranquility of urban environments, making them more attractive for residents and tourists.
- **Lower Carbon Footprint**: Electric ships derive their power from electricity, which can be generated from renewable energy sources such as wind, solar, or hydroelectric power. By utilizing renewable energy, the carbon footprint associated with urban transport can be significantly reduced. On the other hand, trucks heavily rely on fossil fuels, contributing to greenhouse gas emissions and climate change.
- **Congestion Relief and Space:** Urban truck transport often leads to traffic congestion, especially during peak hours. Electric ships provide an alternative mode of transportation, particularly for cargo or bulk goods, which can be transported via waterways. By shifting freight from trucks to electric ships, congestion on roads can be reduced, resulting in smoother traffic flow and reduced travel times for commuters. Less traffic on the streets means more space for e.g. for bike lanes. This is also important when it comes to space for delivery trucks in the city center.

- **Enhanced Waterway Utilization:** Utilizing electric ships for urban transport promotes the use of waterways, such as rivers and canals, as viable transportation routes. This utilization can revitalize waterfront areas, encourage urban development around ports, and improve overall waterway infrastructure.

- **Job Creation:** Transitioning to electric ship transport may create new employment opportunities. The manufacturing, maintenance, and operation of electric ships, as well as the development of charging infrastructure, can generate jobs in various sectors, fostering economic growth and local development.

For potential CO2-savings for a transport on the waterways in Hamburg, the WaCaBa study[16] therefore again compared the savings of a diesel truck with 3.5 tons and 7.5 tons compared to a small and big vessel (for further information see chapter “Determination of the fleet”).

Figure 9.2: Potentials for CO_2-saving - Local CO_2-savings p.a. at 460 Tours/Year



Source: Fraunhofer CML, WaCaBa feasibility study, 2021, Final presentation for AVATAR conference in Hamburg

Based on the calculations of the Fraunhofer CML, a potential electric vessel for urban waterways in Hamburg can save up to 262 tons CO_2 per year compared to a 3.5-ton diesel truck. What is important to mention is that weight-constrained load saves more CO_2 compared to volume-constrained cargo.

Leading the Way for Innovation, adopting electric ships for urban use symbolizes the commitment to innovation and progress. By embracing sustainable technologies, cities become pioneers in the global movement toward a greener future. This inspires others; creating a ripple effect that encourages the adoption of electric ships by starting new pilot projects and use cases, further strengthen the positive impact on CO_2 reduction and environmental preservation, which are only two of many more side effects that have a positive impact.

[16] Fraunhofer CML, WaCaBa feasibility study, 2021, Final presentation for AVATAR conference in Hamburg

10. Tests

Guideline of assessing performance of urban freight vessels in real life has been designed and developed by AVATAR project partner TUD (see Pang, Y.,2022), which includes measurement details of determining main parameters, sensor technologies for (remote) data acquisition, defining operational scenarios to be tested, performance indicators, assessment criteria and methods of risk evaluation. The developed guideline has been discussed with and accepted by project partners regarding testing and assessing the performances of the new AVATAR vessel (incl. Green Wave), Maverick and TUD RAS model scale boats. The guideline has been applied in the testing and demonstration of TUD RAS model vessels for performance assessment and will be used by AVATAR's partners and applied to all AVATAR vessels in the next reporting period. A framework has been developed by SSPA for using AIS-data to analyze the operational performance.

Based on the project report outline developed and the final testing and demonstration results, the 3 reports have been prepared by relevant project partners. The 3 reports include: 1) performance report AVATAR vessel (Geirnaert et al., 2023), 2) performance assessment report Maverick (Shuai et al., 2023), and 3) performance report TUD RAS vessels (Pange et al., 2023).

11. Scenario development for market uptake and recommendations

11.1 Strategy and recommendations

11.1.1 Policy recommendations

This chapter is about the policy recommendations published in Work Package 4, Activity 3 with the Policy Position Paper within the framework of the INTERREG North Sea Region AVATAR project. The entire Policy Position Paper can be downloaded from the AVATAR project website here. The main questions in the Policy Position Paper: "How to foster urban freight transport using waterways?" and "How can (highly) autonomous zero-emission vessels play a role in that?" were summarized in eight key policy-related outcomes of the AVATAR project.

Economic viability of urban freight distribution solutions on waterways are highly dependent on municipal and regional transport policy

The AVATAR project has shown that sustainable city freight distribution on waterways can be economically viable today but remains a challenge, regardless of whether automated ship operations are used or not.

However, active management of inner-city accessibility for commercial road traffic is essential for this. Cities in which this accessibility is limited by regulations or infrastructural features, have established urban waterway transport solutions significantly more often.

- It is not enough to have mobility transition strategies in place. Free accessibility for trucks will always result in high shares of truck deliveries.
- Establish active policies for a mobility transition to foster urban IWT[17], such as zero-emission zones, (temporary) access restrictions, inner city tolls or sustainability incentive schemes in your city.

See the big picture with regard to socio-economic and environmental benefits vs. economic viability

When it comes to socio-economic & environmental benefits created by zero-emission urban IWT, the zero emissions (avoided GHG & pollutants) are only one aspect of those benefits. In contrast to urban IWT, road freight transport generates significant external costs that have to be borne by society, such as health (noise, accidents & fatalities) and congestion. For example in Hamburg – one of the project partner regions - 20 people died in 2021 due to road traffic accidents. In the same year, total accidents involving trucks increased by 8.4%[18].

- Cities and municipalities should ensure that they take external costs into account when assessing the benefits of an urban waterway transport solution.

[17] Inland waterway transport
[18] Free and Hanseatic City of Hamburg: Verkehrssicherheitsbilanz 2021, 02/2022

- When and where possible, external costs of a mode of transport should be internalised, especially in commercial transport, e.g. through infrastructure usage fees[19]. In no mode of transport does this happen to such a small extent as on the roads[20].

Infrastructure needs to be in shape

The decades-long focus on car-oriented cities has led to so-called lock-in effects, which now make it more difficult for alternative modes of transport to establish themselves, for example due to neglected infrastructures (urban canals, quays etc.)[21]. The same is true for last mile distribution via cargo bikes, necessary for many use cases related to urban IWT. When bike lanes are in bad shape or non-existent, this will cause disadvantages for the implementation of use cases.

For (highly) autonomous inland shipping, infrastructure will also have to be adapted accordingly.

- Sustainable car-independent last mile delivery solutions need sufficient infrastructure maintenance and public investments.
- Sufficient and efficient loading and un-loading facilities need to be created in cities as part of the public waterways and canal system infrastructure.

Autonomous (inland) shipping needs a **legal framework**

Many research and innovation initiatives are being pursued worldwide for the development of autonomous and unmanned ships, from global supply chain context to urban IWT use cases. However, these ships' wider adoption is limited by the existing regulatory framework, which presently does not provide clear guide-lines and requirements for the design and operation of autonomous ships. Current regulatory barriers that need to be over-come are[22]:

- Currently, a number of authorities are regulating the operation of the IWT vessels. Existing rules and regulations do not allow for the operation of unmanned vessels on European level as they ex- or implicitly refer to the presence of humans, so adaptations in the regulations are required[23].
- Existing rules and regulations allow testing of unmanned vessels, but within limited scope and area. Wider area testing would require adaptations of the existing regulations, too.

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[19] Germany, Umweltbundesamt: Auf dem Weg zu einer nachhaltigen urbanen Mobilität in der Stadt für Morgen, 05/2021

[20] CE Delft, DG MOVE (European Commission): Handbook on the external costs of transport

[21] Research Group DynaMo: THESEN ZUR NACHHALTIGEN MOBILITÄTSWENDE IN STÄDTEN, 09/2021

[22] World Maritime University (WMU): Regulatory framework analysis for the unmanned inland waterway vessel, Journal of Maritime Affairs, May 2021

[23] More specifically, regulations require the existence of an operator on the vessel for the functions related to navigation, monitoring, emergency and waste management.

* Wider adoption of unmanned IWT vessels would require the development of novel design codes for autonomous ships at national and European level and their continuous update[24].
* Moreover, it is important to assure uniformity between waterways authorities (Belgium for example has different ones) or even countries connected by waterways in regulating autonomous barges. Otherwise, hurdles & costs will raise for ship-owners & discourage them from pursuing businesses with autonomous vessels[25].

Liability frameworks need to be revised for autonomous (inland) shipping[26]

As the role of actors will change fundamentally when inland shipping becomes autonomous, the conventional risk distribution or allocation of liabilities amongst the different stakeholders will not be accepted anymore.

The liabilities framework must be ascertained regarding not only shore / remote control centre responsibilities but also all the ecosystem actors, also traditional ones. The application of current rules to autonomous barges may have disruptive consequences in terms of risks and cost inhibiting the introduction of autonomous systems.

* New definitions of responsibilities are required for the IWT operations and the definition of responsibilities of the Remote Control Centre.
* Crucial actors for the deployment and adaption of liability frameworks, such as insurers, need to be involved in automated inland shipping pilots & legal framework adaptions as early as possible.

Pilots, **pilots, pilots**

Pilots bring insights. Whether it is technical concepts, their TRL[27], use cases, operational experience or liability and risk distribution frameworks. Only by supporting pilots and living labs, innovative solutions like the AVATAR concept can be adopted in the long run. This is true for both, technical testing as well as economic-operational user tests. Like automation, adaption of such innovations is happening in a multi-stage process. Each level of maturity requires further pilots.

* Cities & regions need to actively support and encourage pilots on zero-emission urban IWT, if they want them to happen in their city or region.
* Cities & regions should facilitate cooperation between shippers of goods in order to stimulate bundling of freight flows (e.g. via a neutral distribution hub). Facilitating

[24] R. Negenborn, F. Goerlandt et al: Autonomous ships are on the horizon: here's what we need to know, in: Nature, 27.02.2023
[25] S. Orzechowski (IDIT) & C. Domenighini (University of Antwerp), MSCA EU AUTOBarge project
[26] S. Orzechowski (IDIT) & C. Domenighini (University of Antwerp), MSCA EU AUTOBarge project
[27] Technology Readiness Level

cooperation can also be translated in supporting the sharing of company specific shipping data, co-investing in transhipment locations and/or infrastructure.

- This should be accompanied by sufficient funding schemes on regional, national or transnational level.
- Including co-creation and active involvement of citizens and end users can boost their interest and demand for new solutions, increasing their chances of success and at the same time assuring user-centred solutions.
- Best practice: Flanders is a pioneer in legislation and permits for smart shipping pilots, making the legislator the true accelerator for innovation in shipping.[28]

Leading by example – Cities need to get active with their own use cases

Amongst others, the AVATAR Market Review[29] has shown, that various use cases exist, that are very well fitting for public stakeholders and municipalities to implement use cases themselves. This is either true for public investments like infrastructure works, public buildings or service logistics like waste disposal or return flows.

- Cities can and should implement their own use cases in order to serve as a role model and thus promote the establishment of zero-emission urban IWT.
- Suitable use cases are in particular building material transports, construction site logistics or waste disposal/return flows in the context of public service logistics operations.
- In addition, cities/municipalities have the possibility to impose conditions on private construction projects in order to pro-mote the use of such applications (e.g. with quotas).
- Hint: Mapping existing regional or municipal sustainability and mobility transition strategies (SUMPs etc.) with such regional use cases/pilots on urban IWT can help to learn more about their target contributions to those strategies and also their benefits with regard to external costs of public actions (see point no. 2).

Bureaucracy and fragmented responsibilities **prevent** the **implementation** of innovative solutions

Cities need to give benevolent support and act as enablers instead of brake blocks, especially when it comes to new solutions for which no processes in the regulatory or administrative approval framework are (yet) in place.

- The mere implementation, administration and control of existing regulations is not sufficient to establish urgently needed innovations.
- In particular, the complexity of managing the mobility transition is forcing municipal actors to recalibrate & to readjust their role.30
- This is where the biggest gap currently exists, as municipal actors only very rarely (want to) act as pioneers and enablers in this field.

[28] SEAFAR / AVATAR project
[29] AVATAR project: : Market review on city freight distribution using inland waterways, 2021
[30] Research Group DynaMo: THESEN ZUR NACHHALTIGEN MOBILITÄTSWENDE IN STÄDTEN, 09/2021

- In addition, there is an urgent need to establish better coherence and multi-level governance from the EU level down to the municipalities, as the latter are the decisive key to implementation!

11.2 Concept for action or scenarios

The implementation of use cases is already possible today. The DHL Vessel project in London or the Floating Service Center in Amsterdam are just two of many other good examples in Europe (more in the Market review). However, they are always dependent on specific local conditions, especially favorable infrastructural constraints (narrow streets/old town) or policy implementations that favor alternative waterborne transports (e.g., entry bans, zero emission zones, etc.).

Today autonomous transport is still in its early stages and is more likely to be expected as pilot projects in the coming years rather than fully operational solutions. To establish use cases in suitable cities and municipalities, it is essential to promote and implement pilot experiments.

As a legacy and impact of the AVATAR project, it is gratifying that the majority of identified use cases (see chapter 4 and 5 of this report) could be acquired for new innovative projects with pilot applications. The two identified use cases in Hamburg, called *Parcel Delivery* in Decarbomile and *Retail Shuttle* in InnoWatr 2.0, will be put into practice. In Ghent, three other use cases will also be piloted in the follow-up project InnoWaTr 2.0.

In order to develop an initial understanding for third parties not involved in the project, whether it is worthwhile and effective to consider waterborne use cases, the AVATAR project partners have developed a "Decision Tree" tool. This tool provides a user-friendly interactive source of information as a self-assessment tool for different user groups (e.g. cities, municipalities, logistics service providers, ship operators). More details can be found in the following sub-chapter.

11.3 Decision tree

The goal of the decision tree is to inspire people thinking about the option of (highly) autonomous sailing and city freight distribution, presenting it in an accessible, informative and easy way. Decision takers should be aware of the steps they should consider. “If you want to introduce the concept, did you think about these topics?” -> This is a typical question the Decision Tree highlights. Based on various input documents such as the market study for selected use cases, SWOT/PESTEL, Economic assessment and testing, a Decision Tree is developed.

In Excel **a decision support model** has been created that can be applied to 3 types of stakeholders: owner of the vessel(s), private company that takes decision about type of transport (decision taker; e.g. logistics service provider) and a city (striving for (highly) autonomous sailing in the city). On the basis of a scoring system, each stakeholder will be advised about some research questions. The Excel decision support model has also been translated in a visualized concept.

The decision support model has been applied to 6 cases:

=> Ghent building materials case from the point of view of the 3 stakeholders

=> Hamburg parcel delivery case from the point of view of the 3 stakeholders

Figure 11.1: AVATAR decision tree – Owner of the vessel

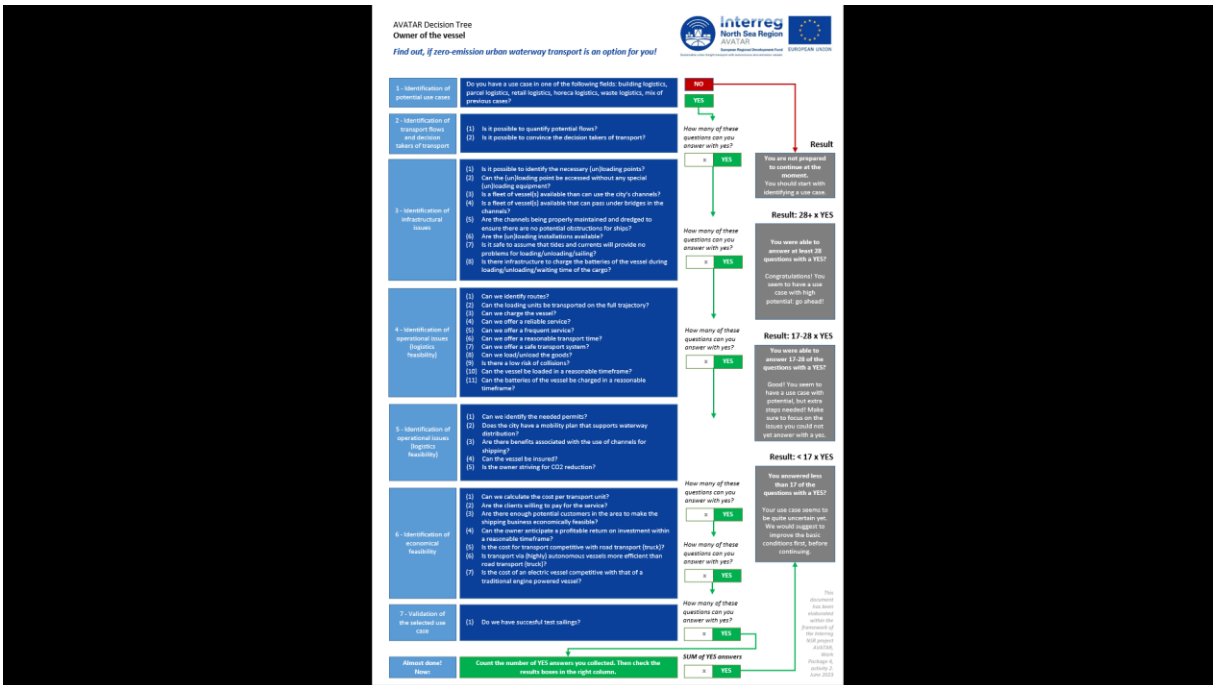


Figure 11.2: AVATAR decision tree – Decision taker

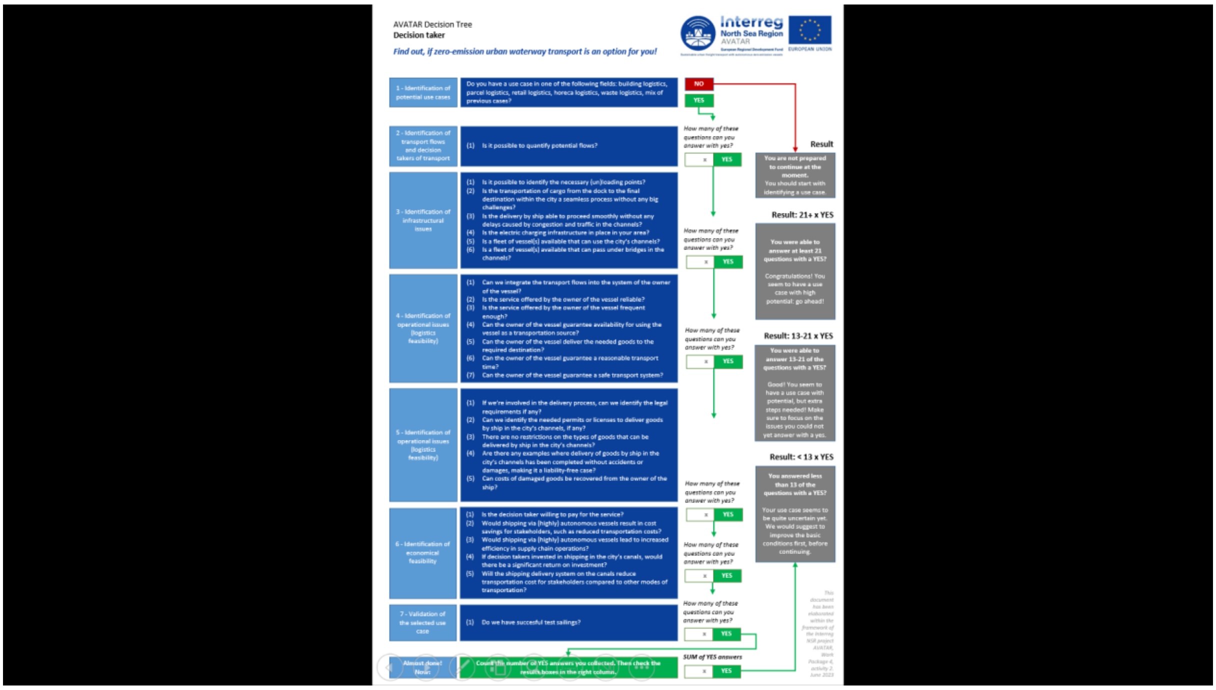
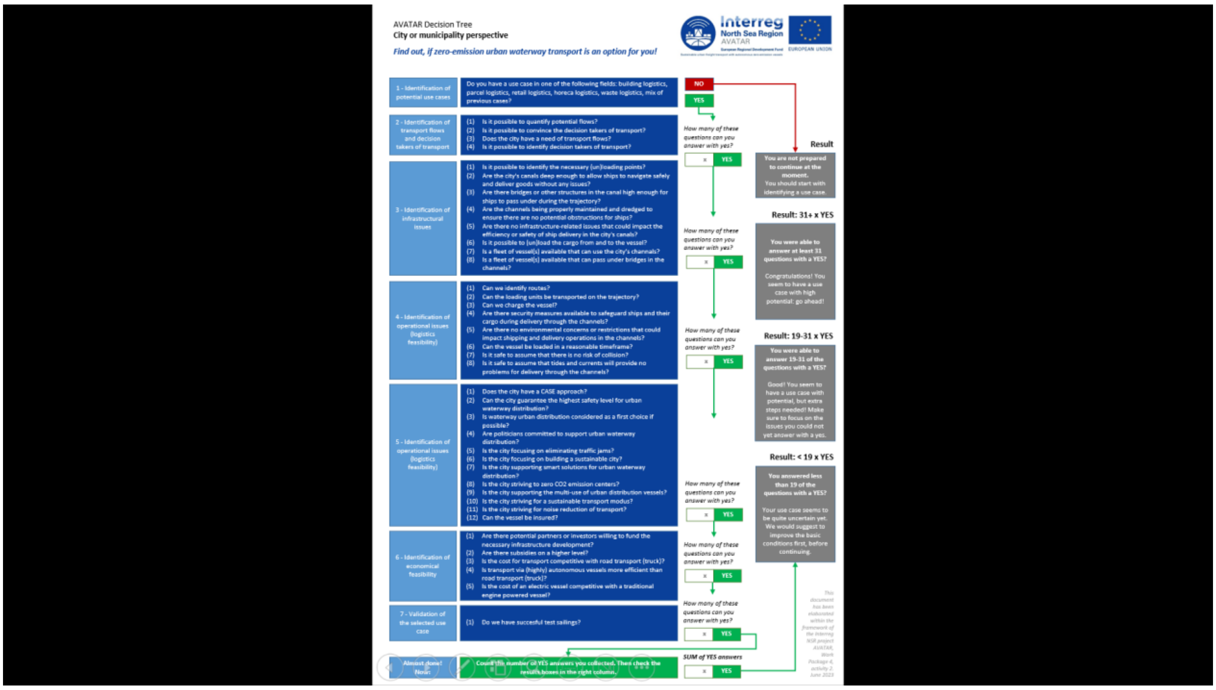


Figure 11.3: AVATAR decision tree – City of municipality



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