IW-NET

Innovation-driven Collaborative European
Inland Waterways Transport Network

D3.2 – New design options for barges with improved navigability

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Executive Summary

As inland waterway transports need to be promoted and low water periods had been more and more common in the last years, our aim was to generate new barges designs, which facilitate navigation on low water levels. First, we decided on a suitable cargo. 45’ high cube containers were taken. On the one hand, containers have a very low density in comparison to e.g. bulk goods and are therefore suitable for navigating on low water conditions and on the other hand 45’ hc containers are widely used for intermodal transportation, which needs to be promoted on the Danube, as container transport on the Danube is hardly carried out today. We decided on operate the route between Enns (Austria) and Giurgiu (Romania) with the new barge designs, as these two ports were among the few which could handle 45’hc containers. We further analyzed locks and bridges to examine the maximum possible heights and breadths of the new barge designs.

Taking the Europe 2b and Europe 3a barges as a basis, we designed six different barges using Naval Architecture CAD. The barge designs were in-depth analyzed regarding their stability and the sightlines resulting in several designs, which could carry only two layers of containers due to limited stability or sight. Furthermore, the construction materials were investigated. Shipbuilding steel is, indeed, even though heavier than aluminum, the better option, regarding stability and price. We concluded that there is no design, which is generally the best one, but it is rather situation dependent.

Furthermore, we took possible further improvements regarding low water navigation into account, such as reducing the height of the side walls of the barge to reduce the total weight or reducing the weight of the cargo. Here we concluded that reducing the height of the side walls would decrease the stability of the barge and necessitate further stabilization, which increases the total weight. Therefore, this option is hardly feasible.

Lastly, we examined transport emissions using barges in comparison to truck transport between our route from St. Florian to Ovidiu. We used a transport example to visualize the CO2 emissions savings by using EcoTransIT and the GLEC framework.

Disclaimer

List of Abbreviations

Abbreviation	Description
ABM	Agent-Based Modelling
AT	ISO 3166-1 alpha-2 country code for Austria
CH	ISO 3166-1 alpha-2 country code for Switzerland
CAD	Computer Aided Design
CEVNI	Code européen des voies de navigation intérieure
BG	ISO 3166-1 alpha-2 country code for Bulgaria
DE	ISO 3166-1 alpha-2 country code for Germany
FR	ISO 3166-1 alpha-2 country code for France
HR	ISO 3166-1 alpha-2 country code for Croatia
HU	ISO 3166-1 alpha-2 country code for Hungary
Inland ENC	Inland Electronic Navigational Chart
NL	ISO 3166-1 alpha-2 country code for The Netherlands
MD	ISO 3166-1 alpha-2 country code for Moldavia
RO	ISO 3166-1 alpha-2 country code for Romania
RS	ISO 3166-1 alpha-2 country code for Republic of Serbia
SK	ISO 3166-1 alpha-2 country code for Slovak Republic
UA	ISO 3166-1 alpha-2 country code for Ukraine
UNECE	United Nations Economic Commission for Europe
VCG	Vertical center of gravity

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1 Introduction

The European Green Deal, announced in 2019, aims to make Europe the first climate-neutral continent by 2050. Therefore, the deal supports several decarbonization targets (European Commission 2019). The mobility sector, including transportation of people and goods, produces 25% of Europe's greenhouse gas emissions and is a key area for decarbonization (Greene and Lewis 2019). The Sustainable and Smart Mobility Strategy, published in 2020, outlines specific goals and measures to reduce transport sector emissions by 90% by 2050 (European Commission 2019).

One of these measures which has been identified to reduce transport emissions is a shift to inland waterway transport (IWT). IWT can reduce negative impacts from road transport, such as emissions, noise, and congestion costs (European Commission 2019). It saves up to 70% of CO2 per ton compared to road transport and has the lowest external costs compared to road and rail due to its low accident rate and limited noise pollution (Greene and Lewis 2019, Fastenbauer et al. 2019). Another great advantage of IWT are the free capacities, particularly on the Danube, where only around 15% of the capacity is being used at the moment (Fastenbauer et al. 2019).

As IWT has a limited network density it is dependent on multimodal transport, with pre-carriage and on-carriage often carried out by road due to the high road network density for collection and delivery (Tavasszy et al. 2015, Blauwens et al. 2006). As containers are most often standardised, and mostly used as an equipment for multimodal transports it is essential to enable and facilitate their transport on inland waterways. While the transport of containers is already common on rivers, such as the Rhine, there are hardly any container transports carried out on the Danube (CCNR 2020). Thus, enabling container transports on the Danube could on the one hand promote multimodality and on the other hand increase the usage of the Danube significantly by attracting new customers (Kawasaki and Matsuda 2015).

To enable efficient multimodal transport while also strengthening inland navigation, a continuous and resilient infrastructure for the involved transport modes is required (Bian et al. 2022, Islam 2018). For IWT this means that there are minimum fairway parameters, such a minimum fairway depth and width, which are needed, to ensure an economic viable transport and a resilient infrastructure (Hoffmann et al. 2014). The IWT infrastructure faces two main challenges, which hamper the deployment of this minimum fairway parameters. Firstly, as a natural resource, inland waterways have uneven riverbeds, which means that the fairway depth of the river can vary throughout the course of the river and throughout a year. This could be a cause for the development of bottlenecks for inland navigation (Beuthe et al. 2014). To maintain a water depth of 2,5m throughout the year maintenance works, such as continuous dredging works, to remove surplus sediment on the rivers are essential (Hoffmann et al. 2014). Secondly, there have been increasingly frequent periods of low water in recent years. Low water means that a river does not carry enough water due to metrological conditions, e.g. droughts. Periods of low water often last for several months and massively hinder inland navigation, as the resulting shallower fairway depth means that ships can bear less cargo. This leads to delayed, unreliable and uneconomical transports (Haselbauer et al. 2014).

Low water is a real concern that can only be counteracted to a limited extent by maintenance work on the river. Rather, other, additional measures are needed to be able to offer economic transport despite the low water conditions. One possibility to improve the navigability on inland rivers in low water periods in to adapt the current available ship designs to the increasingly frequent low water conditions. Therefore, the aim of Task 3.2. of this iw-net project was to design new barge options for an improved navigability in fluctuating water conditions. To focus on fluctuating water levels rather than on low water levels was a decision based on the fact that vessels, which are built specifically for low water, are in most cases less cost-effective at sufficient fairway depth. Therefore, we agreed on designing barge designs for fluctuating water levels.

This deliverable is structured as follows. Chapter two focuses on the boundaries for the new barge design options. In chapter three the new barge designs are presented in detail, followed by an in-depth analysis of the barge designs, including the an analysis of the sightlines and a stability analysis. Further considerations about the barge designs are included in chapter five. The last chapter six compares the transport emissions of a container transport using one of our barge designs with the transport of the same number of containers by road transportation.

2 Boundaries for new barge designs

For being able to design new barge options for fluctuating water levels, we first of all defined boundaries. For their definition, we carried out a cargo analysis, a ports' and a locks' and bridges analysis. Out of the results we defined the maximum breadth and length of the new barge design as well as a route, where the new barge designs should operate and which goods should to be transported.

2.1 Cargo analysis

After intensive discussion with a group of experts in inland navigation on the Danube, we concluded that the new barge designs should be designed for the transport of containers and to focus on non-motorised barges, as this would best fit in with the navigation of pushed convoys, which is the predominant mode of navigation on the Danube. On the one hand, this makes sense from a market perspective, but also from a technical point of view. On it's side, it is important for the Danube to generate new customers. The introduction of container transport, which has hardly existed up to now, offers an opportunity for this. In addition, according to the Green Deal, multimodality on the inland waterway should be promoted. This is also possible through the use of containers, as they are standardised and thus facilitate transhipment from one mode of transport to the other.

From a technical point of view, the transport of containers is particularly relevant with regard to low water, as containers in most cases have a significantly lower density than, for example, bulk goods. Accordingly, they are lighter in weight and induce less vessel draught than heavy goods. Less draught is essential, especially in low water, in order to be able to carry out transports economically viable.

Decision on container type

Standard 20' and 40' containers are merely used for intercontinental, maritime transport (e.g. import/export from Asia to Europe). They provide a capacity of 31 m3 and a payload of 28.330kg (20' container) and 67,5 m with a payload of 32.500kg (40' container). Nevertheless, these standard container types are hardly suitable for domestic hinterland transport within Europe, as the container dimensions are not designed for the transport of Euro pallets (the most common packing aid used in Europe). Loading euro pallets in 20' or 40' containers results in a poor load factor, as it is impossible to use the whole capacity of the container due to their hardly suitable dimensions (20' and 40' containers have a width of 2,35m, while a euro pallet has a dimension of 1,20m x 0,80m, therefore it is neither possible to load three pallets lengthwise, nor two pallets width wise in 20' or 40' containers, thus each container can be loaded with a maximum of 27 euro pallets).

Hinterland transport in Europe is therefore often carried out using so-called **45' pallet-wide High Cube containers.** As the name "pallet-wide" suggests, it is very simple to load Euro pallets in these containers, as the width of the containers is adapted to the dimensions of the Euro pallets. High Cube indicates that the height of the container is larger than a usual 45' container, therefore is offers more loading capacity. The dimensions of a 45' pallet-wide HQ container are the following: 13,716m x 2.,500m x 2,896m, it has a payload of 29.140kg and fits 33-euro pallets. As our aim is to promote multimodal, respectively intermodal hinterland transport in Europe using the newly designed barge options we opted to design the barges to carry these 45' pallet-wide HQ containers.

2.2 Ports analysis

Following the start of the project, the partners chose the transport route and the to be used intermodal units based on the transport flows of company Nothegger and serving for the initially planned demonstrator. Ideally the selected route would connect Austrian ports and ports situated on the lower Danube in the south of Romania (between Corabia and Calarasi). Thereafter the standards of to the intermodal equipment were defined, having in view a lot of factors and in ordern to gain competitive advantage over other transport alternatives. Besides price, flexibility and sustainability, the speed and reliability of a service are key factors to gain market shares and shall be reflected when taking the final decision on the ports to be used.

Definition of possible ports:

Austrian ports: Enns
Vienna
Lower Danube ports: Ruse (Bulgaria)
Giurgiu (Romania)

Definition of intermodal equipment to be used:

a. equipment: mainly 45‘ hc pw containers
l: 13,716 m w: 2,500 m h: 2,896 m max gross weight: 34,000 tons
some 45‘ hc side-curtain (only top layer)
l: 13,716 m w: 2,550 m h: 2,900 m max gross weight: 34,000 tons
some 30‘ ot steel-coil-containers
l: 9,060 m w: 2,440 m h: 2,590 m max gross weight: 34,000 tons
b. interim storage: 90 pcs. of 45‘ hc
c. crane capabilities: weight center point 10m @vertical shore or,
9,60m on barge +crane position @slope quay

As chosen methodology for the in-depth analysis an objectified questionnaire was established to collect the relevant information (see 2.1.1.).
COVID-19, the outbreak of the pandemic situation in December 2019, interrupted locally, regionally, and globally the supply chain of industries. Because of the pandemic situation, as well as due the newly adapted truckers regulative, in the year 2020, on working time, posting and returning back to home countries, a massive change in the transport sector to took place, leading to the situation that the foreseen volumes for the demonstrator were not available any longer.
Reflecting the new situation AIT started analyzing the business catchment-area around every port which brought a better understanding of what the Danube ports could serve if they would be technically fit for multimodal operations. This approach should enable the project to attract new transport volumes, traditionally transported by trucks, to shift onto waterways by using intermodal equipment.
Consequently, the port analyses study were extended to a great extent, including now, each port along the originally chosen route.
Desk research as well as on site visits were leading to the elimination of many smaller ports, due to the fact of not fitting infrastructure in port, rail connections or any other minimum criteria which were defined.

Finally, the port analysis included 13 (thirteen) ports, studied in detail and to defined of suitable to the project.

2.2.1 Questionnaire

Conducting the port analysis many ports were contacted directly to interview and get concrete and clear information. Some of the ports were visited in person due to the difficulties in communication and the lack of trustful information. Most of the difficulties were faced when reaching out to the ports on the lower sector of the Danube. First it was a long process to identify the relevant contact persons and thereafter it was hard to establish communication and receive the needed information for the analysis / research.

Deriving questions from definition:
Question 1:
Can the port load/discharge 45' hc (sc) pw containers | 34,000 tons vertical: @10m distance to vertical shore?
slope quay: @ 9,60m on barge + crane position?
Question 2:
Can the port load/discharge 30' ot steel-coil-containers | 34,000 tons vertical: @10m distance to vertical shore?
slope quay: @ 9,60m on barge + crane position?
Question 3:
If mobile crane – check quay stability!
Question 4:
Interim storage for about 90 pcs. 45' hc pw containers?
Stacked or flat storage? – if stacked, check handling capacity of Reach-Stacker!
Question 5:
Handling hours for shore and river – side?
Question 6:
Customs authorities in port? If yes – working hours?
If no – solution possible? If yes – working hours?

The above questionnaire was applied to all the following ports: Enns, Vienna, Bratislava, Budapest, Novi Sad, Belgrade, Pancevo, Smederevo, Vidin, Calafat, Lom, Giurgiu, Ruse.
Special situation Serbia:
Port of Belgrade was initially selected as relevant due to its geographical position but due to the information that their authorisation was expiring in spring 2021 a more in-depth analysis was not applicable anymore. As deviation possibility, following other ports in the region were taken into consideration: Novi Sad, Pancevo and Smederevo.
Special situation Bulgaria:
Port of Vidin was added to the list considering the existing, but a different cargo volume flow from company Nothegger but was deleted thereafter due to lack of communication from the port authorities and information that no commercial activities are carried out due to lack of infrastructure. As of today, only passenger vessels are operating in this port.

2.2.2 Interview results

After using different methods to collect the information stated in our definition, we classified all the analyzed ports in three (3) categories:

- **fully useable** (meaning that all points are fulfilled),
- **useable with limits** (meaning that some points are missing / most of the time the crane capacity was lower than needed), or
- **not useable** (meaning that most points cannot be fulfilled).

Bellow illustration shows the list of ports and their classification according to the definition:

ENNS / river position: DKM 2112	fully useable
VIENNA / river position: DKM 1920	fully useable
BRATISLAVA / river position: DKM 1865	useable with limits
BUDAPEST / river position: DKM 1865	useable with limits
NOVI SAD / river position: DKM 1253	not useable
PANCEVO / river position: DKM 1152	useable with limits
SMEDEREVO / river position: DKM 1120	useable with limits
CALAFAT / river position: DKM 793	not useable
LOM / river position: DKM 740	not useable
GIURGIU / river position: DKM 493	fully useable
RUSE / river position: DKM 497	fully useable

Table 1: Ports and their classification according to the definition

The detailed results of the research for each port can be found in Table 2 below:

Question 1:	
Can the port load/discharge 45' hc (sc) pw containers | 34,000 tons vertical: @10m distance to vertical shore?	
Enns	STS gantry max. 40 tons @10 m distance
Vienna	Mobile Harbour Crane max. 41 tons @10 m distance
Bratislava	With limits, yes. STS gantry max. 28 tons @10 m distance
Budapest	With limits, yes. STS gantry max. 32 tons @10 m distance
Novi Sad	Currently – No. Development of port is ongoing and shall be finished in 2021. Capacities not known.
Pancevo	Currently – No. max capacity would be @28 tons, distance unknown.
Smederevo	Yes, Mobile Crane max. 140 tons @10 m distance (capacity of cranes and details have to be checked on sight)
Calafat	Currently – No. To invest in mobile crane is under consideration. Could lift 32 tons @10m
Lom	Currently – No. The crane could lift maximum 20 tons @distance not defined.
Giurgiu	Yes, STS gantry max. 34 tons @10 m distance
Ruse	Yes, Port Crane max. 32 tons @distance from quay not defined; (option to tandem lift much heavier containers)

Question 2:	
Can the port load/discharge 30' ot steel-coil-containers | 34,000 tons vertical: @10m distance to vertical shore?	
Enns	Yes, Spreader can also be used for 30' containers
Vienna	Yes, Spreader can also be used for 30' containers
Bratislava	No. Spreader for gantry not available in port.
Budapest	With limits, yes. STS gantry max. 32 tons @10 m distance
Novi Sad	Currently – No. Future spreader will be able to handle all container types.
Pancevo	Unknown
Smederevo	Unknown. (Capacity of cranes and details have to be checked on sight)
Calafat	Currently – No.
Lom	Currently – No.
Giurgiu	Yes, Spreader can also be used for 30' containers
Ruse	Unknown
Question 3:	
If mobile crane – check quay stability!	
Enns	Not applicable
Vienna	Optimal for manipulating containers. They also have a special platform for HEAVY CARGO.
Bratislava	Not applicable
Budapest	Not applicable
Novi Sad	Not applicable
Pancevo	Unknown
Smederevo	Yes. Mobile crane – (quay stability to be checked on sight)
Calafat	Port might be equipped in the future with mobile crane.
Lom	Not applicable
Giurgiu	Not applicable
Ruse	Not applicable
Question 4:	
Interim storage for about 90 pcs. 45' hc pw containers?	
Enns	Possible, capacity available; stacked storage; 40 tons max. capacity of reach stacker
Vienna	Possible, capacity available; stacked storage; 41 tons max. capacity of mobile crane (no reach stacker available)
Bratislava	Possible, capacity available; stacked storage; 45 tons max. capacity of reach stacker
Budapest	Possible, capacity available; stacked storage; 45 tons max. capacity of reach stacker
Novi Sad	Possible, capacity available; stacked storage; not defined max. capacity of reach stacker
Pancevo	Possible, capacity available; unknown if flat or stacked storage; not defined max. capacity of reach stacker
Smederevo	Possible, capacity available; unknown if flat or stacked storage; not defined max. capacity of reach stacker
Calafat	Possible, capacity available; stacked storage; not defined max. capacity of reach stacker
Lom	Possible, capacity available; unknown if flat or stacked storage; not defined max. capacity of reach stacker

Giurgiu	Possible, capacity available; unknown if flat or stacked storage; not defined max. capacity of reach stacker
Ruse	Possible, capacity available; stacked storage; 45 tons max. capacity of reach stacker
Question 5:	
Handling hours for shore and river – side?	
Enns	24 hours - Monday 03:00 through Saturday 12:00
Vienna	Normal working week but if needed 24 hours - Monday through Sunday
Bratislava	Yes, Monday – Friday 06:00 till 22:00
Budapest	Monday – Friday 06:00 till 22:00
Novi Sad	Unknown
Pancevo	Unknown
Smederevo	Unknown
Calafat	Unknown
Lom	Unknown
Giurgiu	Unknown
Ruse	Unknown
Question 6:	
Customs authorities in port? If yes, working hours?	
Enns	Yes, Monday – Friday from 08:00 till 16:00
Vienna	Yes, Monday – Friday from 08:00 till 16:00
Bratislava	Monday – Friday 07:00 till 19:00
Budapest	Monday – Friday 07:00 till 19:00
Novi Sad	Monday – Friday 08:00 till 15:00
Pancevo	Unknown
Smederevo	Unknown
Calafat	Yes, working hours unknown
Lom	Unknown
Giurgiu	Yes, Monday – Sunday from 07:00 till 23:00
Ruse	Yes, working hours unknown

Table 2: Detailed results of ports analysis

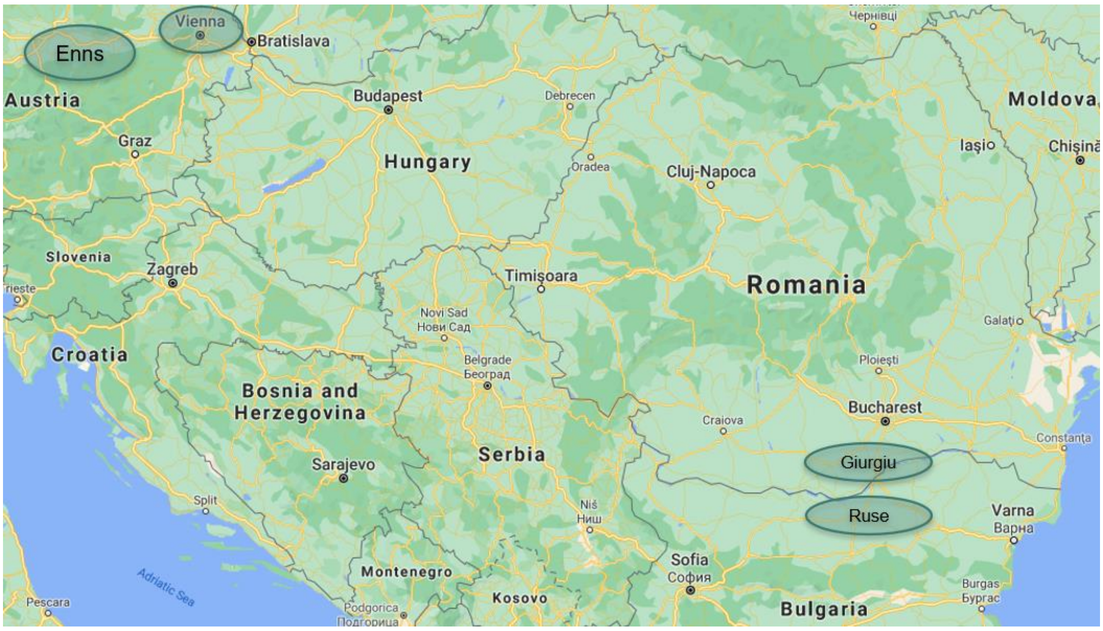

Figure 1: Map with the overview of the fully usable ports

2.2.3 Route decision

Port of Enns was chosen as starting point because it fulfilled all technical requirements and serves in general as hub for business and cargo opportunities. Additionally, the port offers, directly at the quay side, a gantry crane, enabling fast and reliable transfer of inter modal equipment.

Alternatively, the port of Vienna could be used as start/end point. It fulfills all the defined criteria as well but operating with a mobile crane.

Which of the two ports to be used, should be determined by the flows of cargo for the first or last mile, considering the most efficient and environmentally friendly option.

As start/end port on the lower Danube, the Port of Giurgiu (High Performance Green Port of Giurgiu) seems to be the most suitable choice. This derives from the analysis of the technical requirements, and in addition it allows transshipment of cargoes under any weather conditions as the quay side for unloading vessel is fully integrated and inside a covered building.

However, as the High-Performance Green Port of Giurgiu was only inaugurated in the mid of 2021, it still misses a spreader to manipulate diverse types of intermodal equipment. However, it was considered as small but feasible investment as all other requirements are fulfilled, and it is state of the art on the lower Danube.

Alternatively, the port of Ruse (Bulgaria) – situated opposite the port of Giurgiu on the south riverbank – could be taken into consideration. However, it has older infrastructure and utilities but serves all requirements according to the defined analysis. Nevertheless, it is necessary to point to the fact, that during the analysis it was extreme difficult to access technical data and to receive concrete service description/offering, due to the lack of communication and willingness of cooperation.

Wrapping up the research and analysis, it can be concluded that currently many of the Danube ports have a very low degree of modernization and readiness level to handle intermodal businesses. The catchment area analysis provided the fundamental basics, that with only one, maximum two additional ports, multimodality would be possible, serving main metropolitan and industrial areas in between Linz (Austria) and Bucharest (Romania). Considering the NAIADES III plans of the European Commission the basic outcome of the analysis might serve for further decision-making.

2.3 Locks and bridges analysis

Detailed data on dimensions of locks and bridges is in general only available at the national/regional/local waterways administrations. Relevant nautical information for shipmasters is mainly provided by way of Inland ENCs. However, a consolidated overview of infrastructural restrictions covering the entire Rhine-Main-Danube corridor and with a focus on logistics management was not available.

In order to close this gap a consolidated table was drawn up (see Annex 1), containing the following data:

- ports – country, river-km
- bridges – country, river-km, width, clearance, reference gauge
- locks – country, river-km, width, length, clearance, reference gauge
- junctions (to other inland waterways) – country, river-km

For all dimensions a distinction has been made between actual physical dimensions and applicable regulatory restrictions (e.g., for locks the physical width may be 24 m but the applicable navigational police regulations restrict the maximum breadth of vessels and convoys to 23 m).

This analysis has been carried out for the following waterways and waterway sections:

- Danube from river-km 0,01 (port of Ust-Dunaysk, UA) to river-km 2414,25 (Kelheim, DE)
- Danube-Black Sea-Canal from canal-km 0,00 (port of Constanta, RO) to canal-km 65,00 (Cernavoda, RO)
- Main-Danube-Canal from canal-km 0,00 (Bamberg, DE) to canal-km 170,70 (Kelheim, DE)
- Main from river-km 0,00 (Mainz, DE) to river-km 384,00 (Bamberg, DE)
- Rhine-Waal from river-km 151,58 (Rheinfelden, CH) to river-km 956,20 (Gorinchem, NL)

The data was collected from the following sources:

- http://www.viadonau.org/en/economy/the-danube-transport-axis/locks
- http://www.viadonau.org/fileadmin/content/viadonau/05Wirtschaft/Dokumente/2020/20200804_Danube_Bridges_int._deu.pdf
- https://at.d4d-portal.info/
- https://www.danube-logistics.info/danube-ports/
- https://www.danubeportal.com/bottleNeck
- https://www.acn.ro/index.php/en/locks-ports-bridges-charts/239-cernavoda-lock
- https://www.acn.ro/index.php/en/inland-rules
- https://www.acn.ro/index.php/en/locks-ports-bridges-charts/238-agigea-lock
- https://de.wikipedia.org/wiki/Liste_der_Main-Donau-Schleusen
- https://www.elwis.de/DE/Schifffahrtsrecht/Verzeichnis-Rechtsverordnungen-Gesetze-Richtlinien/BinSchStrO.pdf?__blob=publicationFile&v=37
- Verzeichnis der Brückendurchfahrtshöhen/-breiten im Bezirk GDWS Standort Würzburg, Okt. 2017
- https://de.wikipedia.org/wiki/Liste_der_Mainstaustufen
- https://de.wikipedia.org/wiki/Rheinschifffahrt

- https://port-of-switzerland.ch/hafenservice/schifffahrtsservice/inland-enc-hochrhein/
- http://www.vnf.fr/ecdis/ecdis.html
- https://www.elwis.de/DE/dynamisch/IENC/
- https://www.eurisportal.eu/

It shall be duly noted that in autumn 2022 the EURIS portal (https://www.eurisportal.eu/) has been launched, where the data provided by European waterways administrations can be accessed at a central information portal, however, there is still no consolidated synopsis available as elaborated within the IW-NET project. Furthermore, the EURIS portal so far does not clearly display whether the data given represent actual physical dimensions of e.g. locks or are based on regulatory restrictions.

2.3.1 Minimum dimensions for selected waterway sections

As pointed out in 2.1 Cargo analysis it was decided to focus on non-motorised barges only due to their suitability for Danube navigation and the widely used pushed convoys. The suitability of a certain barge design for a specific section of inland waterway has to take into account the following dimensions:

2.3.1.1 *Length*

The length of a specific barge design has in particular to be assessed with a view to possible convoy formations. Restrictions for the length can either be determined by actual physical dimensions of e.g. locks or by navigational police regulations (e.g. § 11.01 (4) of the Rhine Navigation Police Regulation (Rheinschifffahrtspolizeiverordnung).
With a view to the passage of locks also the length of a suitable pusher has to be taken into account, the length range of which is between around 25 and 40 m.

2.3.1.2 *Breadth*

For the breadth of a barge more or less the same considerations apply as for the length, for example, the permitted maximum breadth of vessels and convoys for passing the Main-Danube Canal is 11,45 m (cf. § 12.02 of the German Inland Waterways Traffic Regulation (Binnenschifffahrtsstraßen-Ordnung)). In addition, a further factor can be the port infrastructure for loading and unloading of cargo (e.g., reach of container cranes).

2.3.1.3 *Draught*

The draught of a barge can be seen as the the most variable or flexible of the principal dimensions as it is determined predominantly by the degree of loading. However, the shape of the barge (in combination with the lightship weight) determines the capacity for carrying cargo at a certain draught. In general, a shoe-box-like shape would represent the best usage of Archimedes' principle, but mainly for the purpose of reducing hydrodynamic resistance the "shoebox utilisation rate", correctly addressed in terms of naval architecture as "block coefficient", of a common inland cargo barge lies in a range between approximately 0,85 to 0,9.

2.3.1.4 *Lock dimensions*

2.3.1.4.1 Main-Danube-Canal

Along the Main-Danube-Canal there are 16 locks, all with a physical length of 190 m and a physical width of 12 m. In accordance with § 12.02 of the German Inland Waterways Traffic

Regulation (Binnenschifffahrtsstraßen-Ordnung) the maximum dimensions of a vessel or convoy are limited to 90,00 m in length and to 11,45 m in breadth, however, for single vessels with active bow-steering equipment (e.g. bow-thrusters) the maximum length may be increased to 135,00 m, for convoys where the forward-most vessel is equipped with a bow-thruster or similar the maximum length may be increased to 190,00 m.

2.3.1.4.2 Danube

Along the Danube there are 18 locks in total. The physical lengths of the locks vary between 190 m and 310 m, with a majority of 10 locks having a physical length of 230 m. The physical widths of the locks vary between 12 m and 34 m, with a majority of 13 locks having a physical width of 24 m.

				Lock chambers		
No.	Lock/power plant	Country	River-km	Length (m)	Width (m)	Number
1	Bad Abbach	DE	2,397.17	190.00	12.00	1
2	Regensburg	DE	2,379.68	190.00	12.00	1
3	Geisling	DE	2,354.29	230.00	24.00	1
4	Straubing	DE	2,327.72	230.00	24.00	1
5	Kachlet	DE	2,230.60	226.50	24.00	2
6	Jochenstein	DE/AT	2,203.20	227.00	24.00	2
7	Aschach	AT	2,162.80	230.00	24.00	2
8	Ottensheim-Wilhering	AT	2,147.04	230.00	24.00	2
9	Abwinden-Asten	AT	2,119.75	230.00	24.00	2
10	Wallsee-Mitterkirchen	AT	2,095.74	230.00	24.00	2
11	Ybbs-Persenbeug	AT	2,060.29	230.00	24.00	2
12	Melk	AT	2,038.10	230.00	24.00	2
13	Altenwörth	AT	1,980.53	230.00	24.00	2
14	Greifenstein	AT	1,949.37	230.00	24.00	2
15	Freudenau	AT	1,921.20	275.00	24.00	2
16	Gabčíkovo	SK	1,819.42	275.00	34.00	2
17	Đerdap/Porțile de Fier I	RS/RO	942.90	310.00*	34.00	2
18	Đerdap/Porțile de Fier II	RS/RO	863.70 862.85	310.00	34.00	2

Source: viadonau

*The lock Đerdap / Porțile de Fier I consists of two consecutive lock chambers which require two-stage lockage

Lock facilities along the Danube

Table 3: Locks along the Danube

2.3.2 Conclusions for barge design

The most significant infrastructure restrictions with a view to barge design apply to the river Main and the Main-Danube-Canal, which constitute the link between two of the most important inland waterway regions of mainland Europe, the Rhine and the Danube regions.

The restrictions resulting from infrastructure are in particular relevant to container transport as the vertical clearance of the lowest bridge along the Main amounts to just 4,45 m at HSW (highest navigable water level = 340 cm at water level gauge Würzburg) (Alte Mainbrücke Würzburg, river-km 252,32). At average water level conditions (MW = 174 cm) the vertical clearance at this bridge is 6,11 m. Container load is therefore in general restricted to a maximum of 2 layers for loaded containers and can even be restricted to only a single layer of empty containers, depending on the actual water level, the type of vessel and the type of container (standard vs. high-cube).

For a first assessment of the relation between lock dimensions and barge size the “classic” Europa 2b barge with a length of 76,50 m and a breadth of 11,45 m has been used as a benchmark.

2.3.2.1 *Lock dimensions vs. barge dimensions – length*

With a view to an optimised utilisation of the lock capacity and assuming a push boat with 30 m in length and an overall safety margin of 2 m the maximum possible length of barges can be calculated as follows:

Length of lock	Length after safety margin	Length without push boat	Possible No. of Europa 2b barges	Max. possible length of barges
190 m	185 m	153 m	2	76,50 m
226,50 m	224,5 m	194,5 m	2	97,25 m
227 m	225 m	195 m	2	97,50 m
230 m	228 m	198 m	2	99,00 m
275 m	273 m	243 m	3	81,00 m
310 m	308 m	278 m	3	92,66 m

Table 4: Max. possible length of barges according to locks' length

2.3.2.2 *Lock dimensions vs. barge dimensions – breadth*

The same calculation like for the length can also be performed for the breadth of barges in relation to the physical width of locks. In this case a safety margin of 0,50 m has been taken into account.

Width of lock	Width after safety margin	Possible No. of Europa 2b barges	Max. possible breadth of barges
12 m	11,5 m	1	11,5 m
24 m	23,5 m	2	11,75 m
34 m	33,5 m	2	16,75 m
For variant Europa 2b with B = 11,00 m			
34 m	33,5 m	3	11,16 m

Table 5: Max. possible breadth of barges according to locks' breadth

2.3.2.3 *Conclusions*

In general, there is very limited leeway for improved or optimized barge dimensions with a view to a good utilization of existing infrastructure. Unfortunately, the existing infrastructure does not lend itself to a logical size matrix – e.g. 24 m wide locks would allow two 11,75 m broad vessels alongside, while in order to fit three barges alongside into the larger 34 m wide locks on the Danube the maximum breadth of such barges would be limited to 11,16 m.

For all further considerations on barge design therefore the following limits have been applied:

Maximum length 97,50 m
Maximum breadth 11,45 m

These dimensions are considered to be an acceptable compromise between lock utilization and sufficient flexibility with a view to the accommodation of 45’ high-cube containers.

2.4 Synthesis

After carrying out an infrastructural analysis bridges and locks on the Danube to identify the maximum possible dimensions of our new barge design options, an analysis of suitable cargo to be transported and an analysis of ports, which have suitable equipment to handle and transship containers, we defined the following boundaries for our new barge design options for fluctuating water conditions.

We agreed on containers, as cargo to be carried by our newly designed barge options. Firstly, to promote multimodality and to attract new customers on the Danube. Secondly, because containers have a low density in comparison to other goods and are therefore particularly suitable for low water conditions. More precisely, 45’ pallet-wide high-cube containers were defined. The new barge design options, which will be presented in Chapter three, should be designed to serve on the Danube, between the port of Enns (Austria) and Giurgiu (Romania), as both ports have sufficient equipment to handle and transship 45’ pallet-wide high-cube containers. According to the maximum measures of the barge designs, the analysis of locks and bridges revealed that a maximum length of 97,50 m and a maximum breadth of 11,45 m should be considered.

3 New barge designs

Based on the Europe 2b and Europe 3a barges, six new barge designs were developed. The chapters below describe the new barge designs one by one, addressing various characteristics, such as sight lines, stability and capacity of each barge.

3.1 Initial thoughts

As already elaborated in detail in Chapter 2 above, feasible dimensions for new barge designs are determined by the infrastructure conditions of the inland waterways where they are intended to navigate.

With a view to seamlessly integrate inland water transport into existing logistics chains it is essential for the barges to be able to carry 45' high-cube units, as these are the predominant types for road and rail transport in mainland Europe.

3.2 Design options

The following sub-chapters show the six new barge designs in detail.

3.2.1 001 Europa 2b

The Europa 2b barge can be seen as a typical "workhorse" of European inland navigation. For the analysis of design options for new barges within the IW-NET project it serves as a benchmark for comparison purposes.
A large number of barges of this type or with slightly varied main dimensions can be found in operation on the European inland waterways for a wide range of different cargoes (bulk, containers, high and heavy etc.).

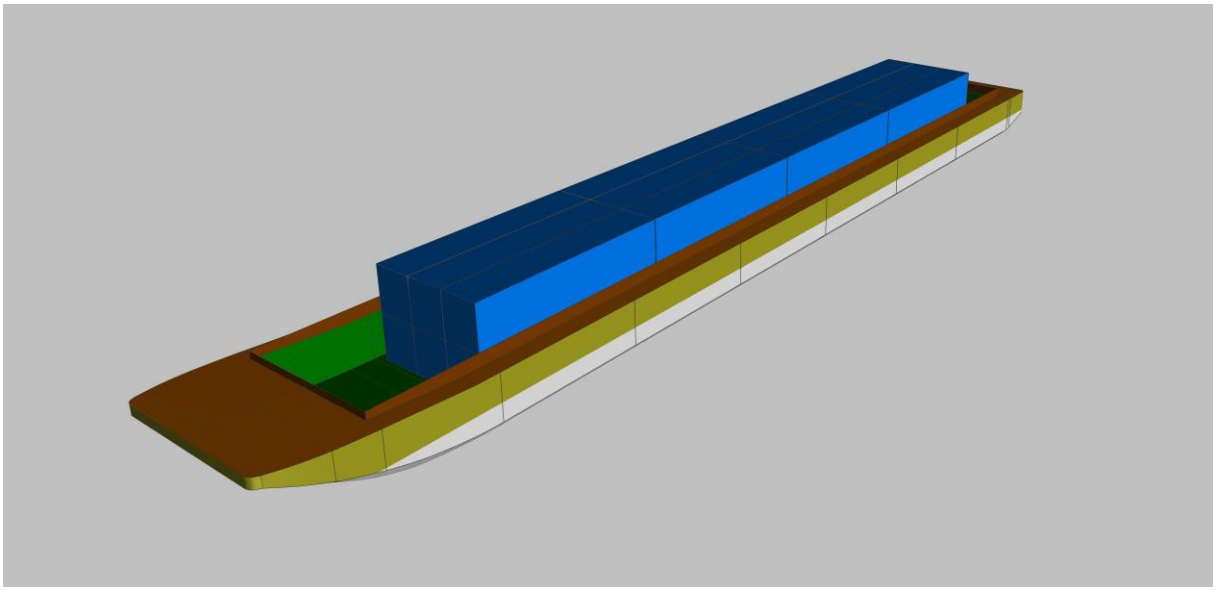

Figure 2: CAD perspective view of Europa 2b barge with 2 layers of 45' high-cube containers

Principal characteristics:

Length over all:	76,50 m
Breadth over all:	11,45 m
Weight of empty barge:	ca. 215 t

Carrying capacity:	24 high cube 45' units in 2 layers approx. 60 TEU in 2 layers
Draught empty:	ca. 0,31 m
Draught with empty containers:	ca. 0,46 m
Draught @ 70% full:	ca. 1,07 m
Draught with full containers:	ca. 1,32 m
Specific draught (additional draught per full container):	42 mm

General arrangement plan: see Annex 2
Lines Plan: see Annex 3

3.2.2 002 Europa 3a

The Europa 3a barge is the "big sister" of the Europa 2b barge and also serves as a benchmark for comparison purposes within the IW-NET project.

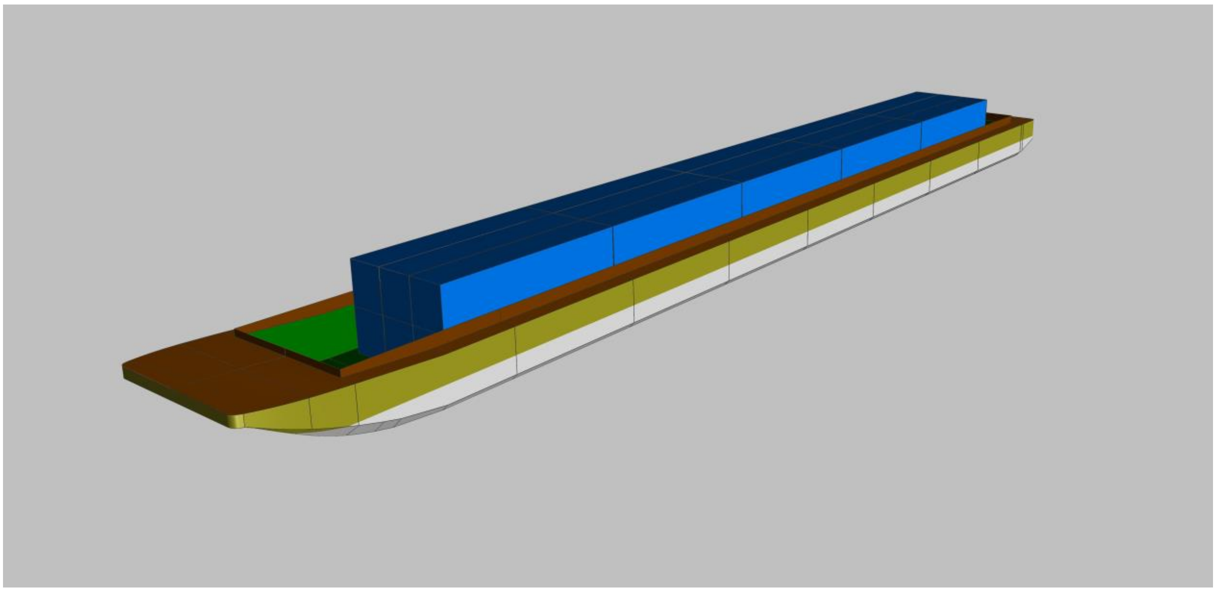

Figure 3: CAD perspective view of Europa 3a barge with 2 layers of 45' high cube containers

Principal characteristics:

Length over all:	90,00 m
Breadth over all:	11,45 m
Weight of empty barge:	ca. 333 t
Carrying capacity:	30 high cube 45' units in 2 layers approx. 72 TEU in 2 layers
Draught empty:	ca. 0,39 m
Draught with empty containers:	ca. 0,54 m
Draught @ 70% full:	ca. 1,18 m
Draught with full containers:	ca. 1,44 m
Specific draught (additional draught per full container):	35 mm

General arrangement plan: see Annex 4
Lines Plan: see Annex 5

3.2.3 003 IW-NET – 3 units abreast

The general idea behind the design of the "IW-NET – 3 units abreast" barge is to tightly fit the principal geometry of the Europa 2b and Europa 3a barges around a container stack of 3 by 5 by 2 45' high-cube containers; i.e. in particular to reduce the width of the barge to the width necessary for the cargo hold and two side decks in accordance with the applicable statutory technical requirements and to fit a bow and a stern section similar to the Europa barges to the cargo hold lengthwise.

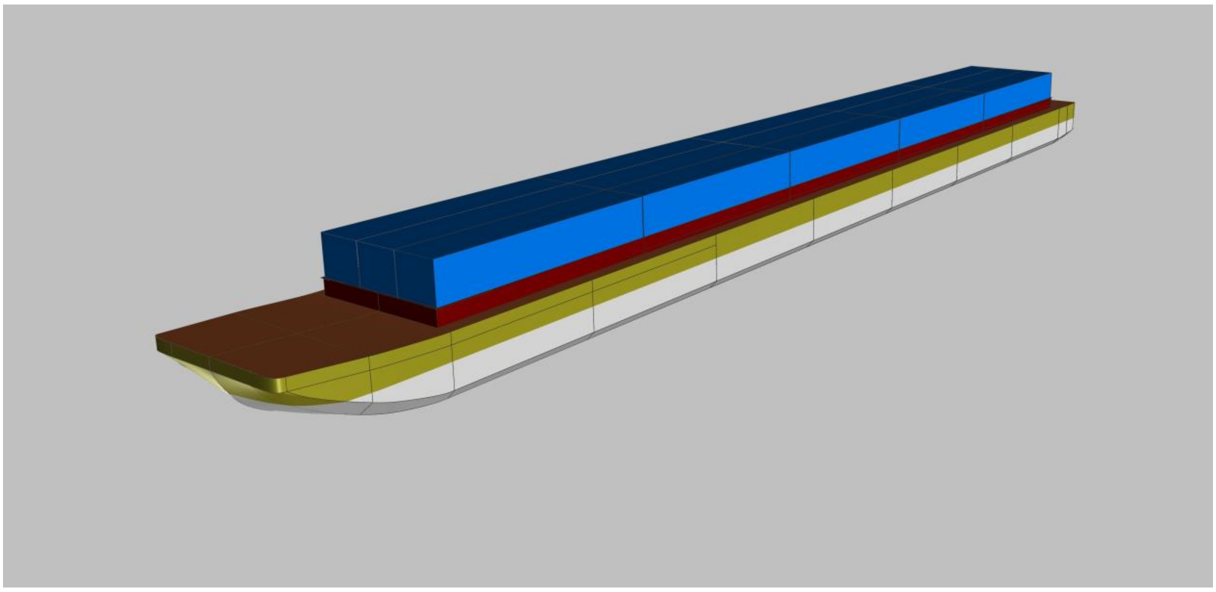

Figure 4: CAD perspective view of IW-NET – 3 units abreast barge with 2 layers of 45' high cube containers

Principal characteristics:

Length over all:	81,00 m
Breadth over all:	9,50 m
Weight of empty barge:	ca. 275 t
Carrying capacity:	30 high cube 45' units in 2 layers approx. 66 TEU in 2 layers
Draught empty:	ca. 0,42 m
Draught with empty containers:	ca. 0,62 m
Draught @ 70% full:	ca. 1,44 m
Draught with full containers:	ca. 1,78 m
Specific draught (additional draught per full container):	45 mm

General arrangement plan: see Annex 6
Lines Plan: see Annex 7

3.2.4 004 IW-NET NEWS Evolution

This barge design is based on a design developed within the 7th FP research programme NEWS where Kanzlei Anzböck was a participant. The general idea is to optimise existing barge designs (namely Europa 2b and Europa 3a) for container transport by replacing the two side decks with a center walkway and to create container bays in order to fit 4 rows of (ISO-) containers abreast. The evolution within IW-NET takes into account the need to accommodate in particular 45’ high-cube pallet-wide containers in order to facilitate integration of inland navigation into logistics chains in mainland Europe (i.e. in particular pre- and post-run by road or rail instead of seagoing vessel).

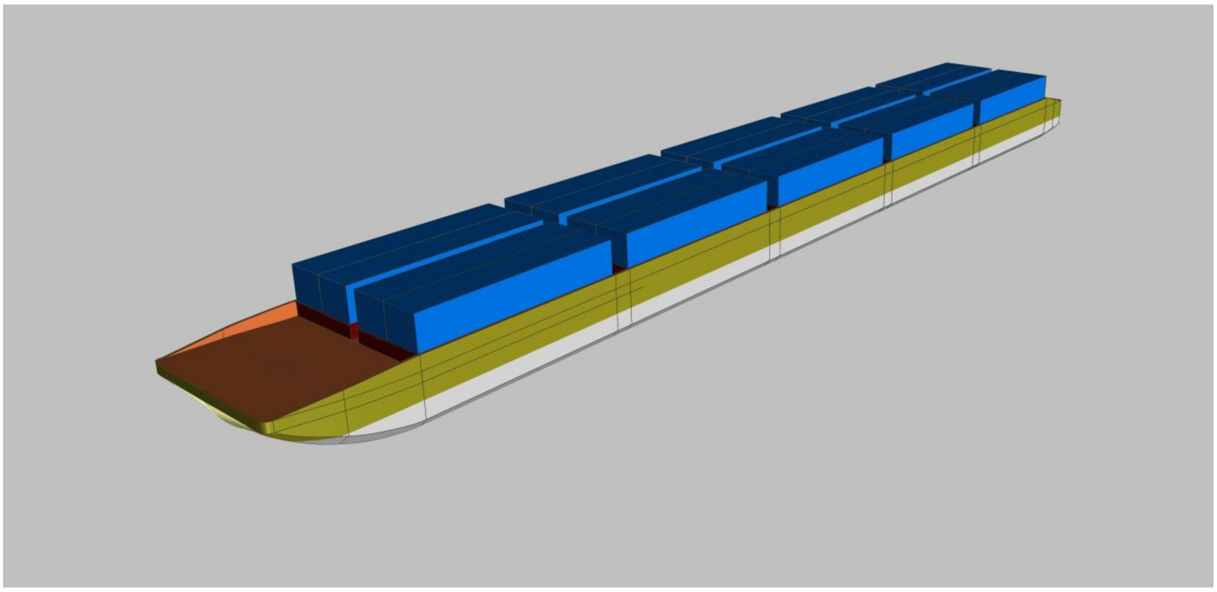

Figure 5: CAD perspective view of IW-NET NEWS Evolution barge with 2 layers of 45' containers

Principal characteristics:

Length over all:	85,92 m
Breadth over all:	11,45 m
Weight of empty barge:	ca. 402 t
Carrying capacity:	40 high cube 45’ units in 2 layers approx. 80 TEU in 2 layers
Draught empty:	ca. 0,46 m
Draught with empty containers:	ca. 0,67 m
Draught @ 70% full:	ca. 1,52 m
Draught with full containers:	ca. 1,88 m
Specific draught (additional draught per full container):	35 mm

General arrangement plan: see Annex 8

Lines Plan: see Annex 9

3.2.5 005 IW-NET containers transverse

This design is the result of an attempt at “thinking out of the box”. Instead of the usual length-wise placement of the containers in this design option for the containers are arranged transverse to the longitudinal center plane. Naturally, this results in a much broader barge, which does not fit into the usual convoy patterns etc. However, it was nevertheless considered worthwhile to include this option in the analysis.

With a view to the breadth of the barge it would not be possible to pass the locks on the upper Danube (upstream of Regensburg) an on the Main-Danube-Canal.

Considering the low grade of compatibility of this barge for convoy formations the basic design might be converted into a self-propelled motor cargo vessel, however, the further elaboration of such a vessel would be out of the scope of this project.

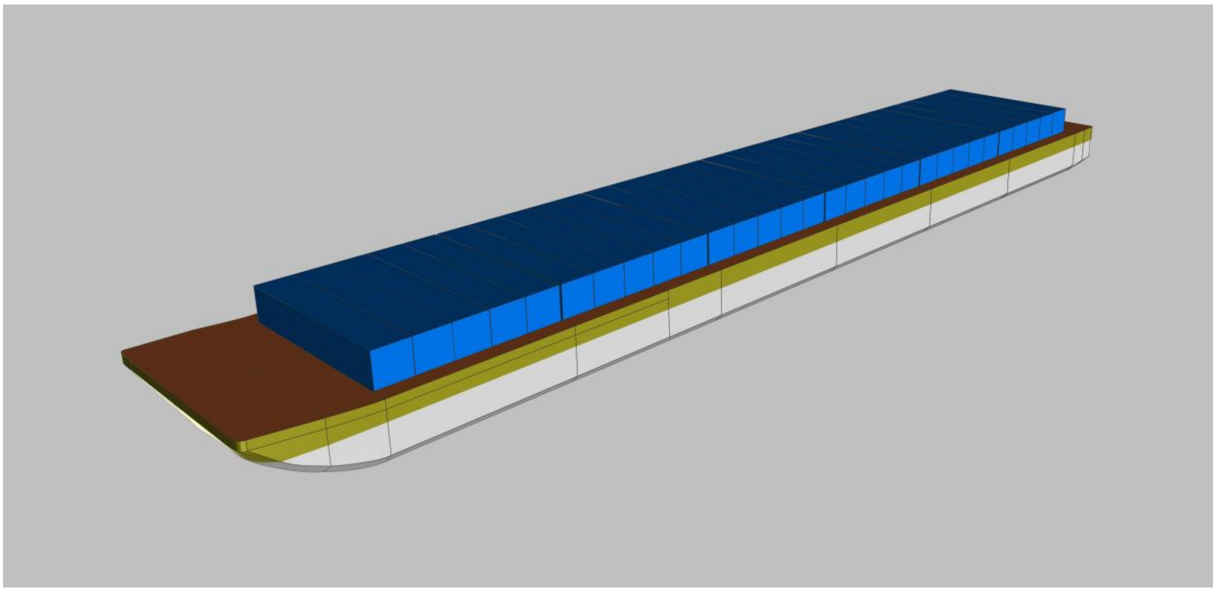

Figure 6: CAD perspective view of IW-NET containers transverse with two layers of 45' high cube containers

Principal characteristics:

Length over all:	89,80 m
Breadth over all:	16,28 m
Weight of empty barge:	ca. 540 t
Carrying capacity:	60 high cube 45’ units in 2 layers approx 120 TEU in 2 layers
Draught empty:	ca. 0,42 m
Draught with empty containers:	ca. 0,64 m
Draught @ 70% full:	ca. 1,50 m
Draught with full containers:	ca. 1,86 m
Specific draught (additional draught per full container):	24 mm

General arrangement plan: see Annex 10
Lines Plan: see Annex 11

3.2.6 006 IW-NET 3 units abreast long

This version is a variation of the IW-NET 3 units abreast barge, lengthened to accommodate an additional stack of containers.

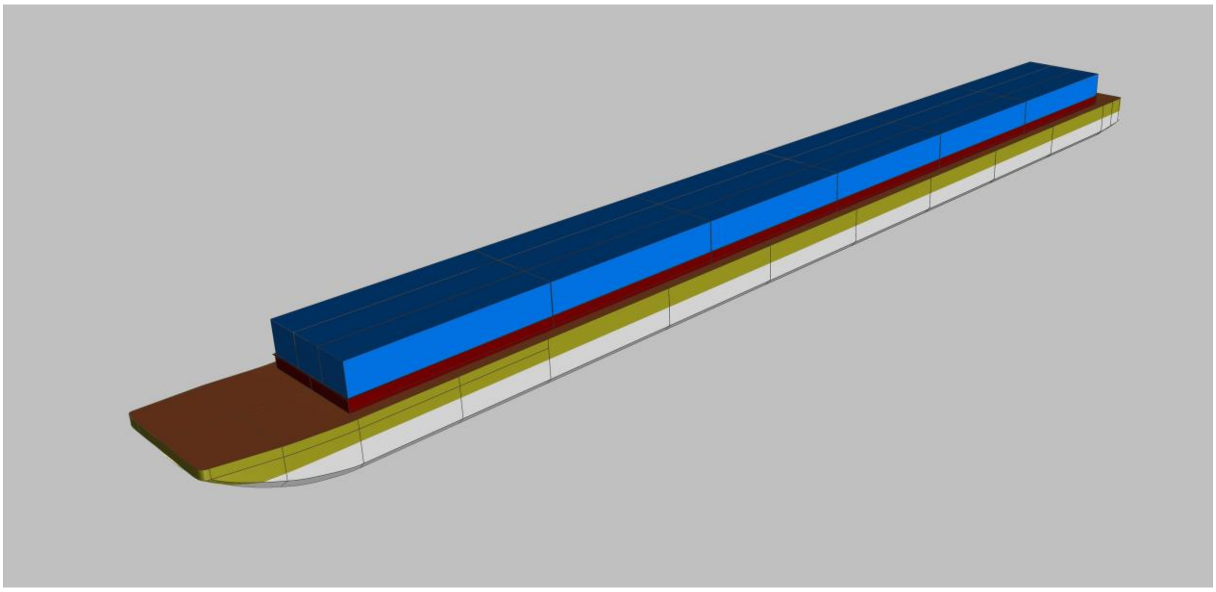

Figure : CAD perspective view of IW-NET 3 units abreast long with two layers of 45' high cube containers

Principal characteristics:

Length over all:	94,77 m
Breadth over all:	9,50 m
Weight of empty barge:	ca. 363 t
Carrying capacity:	36 high cube 45' units in 2 layers approx. 78 TEU in 2 layers
Draught empty:	ca. 0,46 m
Draught with empty containers:	ca. 0,67 m
Draught @ 70% full:	ca. 1,50 m
Draught with full containers:	ca. 1,86 m
Specific draught (additional draught per full container):	39 mm

General arrangement plan: see Annex 12
Lines Plan: see Annex 13

3.2.7 007 IW-Net NEWS Evolution long

This variation of the IW-NET NEWS Evolution barge has been designed with 6 instead of 10 container bays, however, the individual container bays can accommodate 2 lengths of 45’ high cube containers instead of just one. This variation therefore provides higher flexibility for other container types, for example being capable of receiving 3 lengths of 30’ containers or 4 lengths of 20’ containers in the container bays.

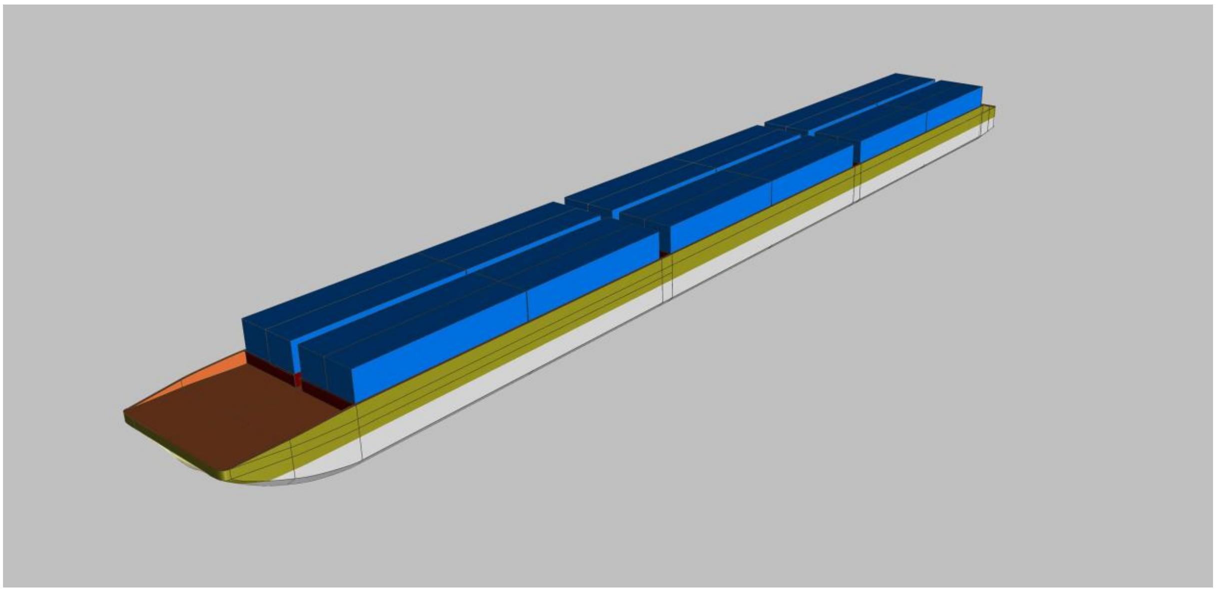

Figure 7: CAD perspective view of IW-NET NEWS Evolution long with two layers of 45' high cube containers

Principal characteristics:

Length over all:	97,32 m
Breadth over all:	11,45 m
Weight of empty barge:	ca. 489 t
Carrying capacity:	48 high cube 45’ units in 2 layers approx. 96 TEU in 2 layers
Draught empty:	ca. 0,49 m
Draught with empty containers:	ca. 0,71 m
Draught @ 70% full:	ca. 1,61 m
Draught with full containers:	ca. 1,99 m
Specific draught (additional draught per full container):	31 mm

General arrangement plan: see Annex 14
Lines Plan: see Annex 15

3.2.8 008 IW-NET 3 units abreast long-shallow

This design is a further variation of the IW-NET 3 units abreast barge, which keeps the container hold of the “long” variation while at the same time increasing the breadth to 11,45 m (instead of 9,50 m). The changes provide additional buoyancy, thus improving the shallow water capabilities, and also more favorable stability characteristics than the other two variations.

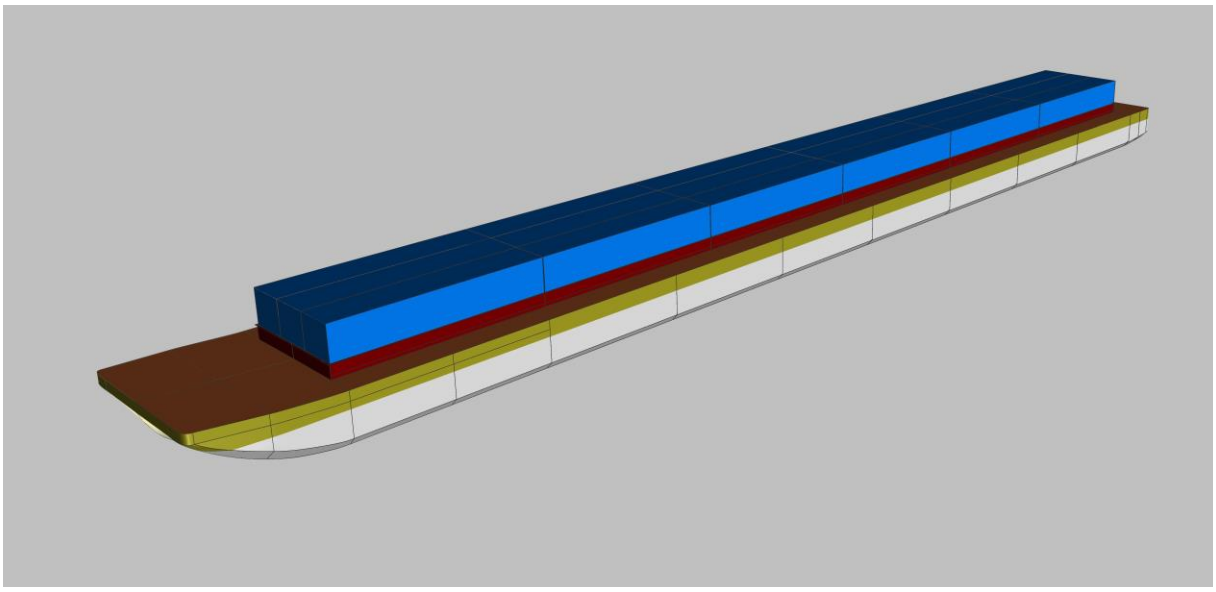

Figure 8: CAD perspective view of IW-NET 3 units abreast long-shallow with two layers of 45' high cube containers

Principal characteristics:

Length over all:	94,77 m
Breadth over all:	11,45 m
Weight of empty barge:	ca. 480 t
Carrying capacity:	36 high cube 45’ units in 2 layers approx. 78 TEU in 2 layers
Draught empty:	ca. 0,50 m
Draught with empty containers:	ca. 0,67 m
Draught @ 70% full:	ca. 1,36 m
Draught with full containers:	ca. 1,66 m
Specific draught (additional draught per full container):	32 mm

General arrangement plan: see Annex 16
Lines Plan: see Annex 17

3.3 Synthesis

Concluding from the assessment of the various design options presented above it can be stated that there is no single optimum solution. Barge design will always need to be optimized for a concrete application and to the specific requirements of its future operator, taking into account the available infrastructure for the intended area of navigation.

However, as the examples presented above show, there is considerable room for improvement in comparison to currently available barge types (001 Europa 2b and 002 Europa 3a) with a view to accommodating 45’ high-cube pallet-wide containers, which are widely used in road and rail transport across Europe. A minimum number of 30 45’ containers per barge has been tentatively identified by the IW-NET logistics partners as the necessary threshold to achieve competitive freight rates in comparison to road and rail transport in the Danube corridor, depending on currently highly volatile boundary conditions (e.g. fuel prices, return requirement for trucks in accordance with Regulation (EU) 2020/1055). This minimum container capacity cannot be achieved with standard Europa 2b barges and only just with the (considerably less abundant) Europa 3a barges, while all new design options at least reach this threshold, most of them even exceeding it considerably.

4 In-depth analysis of new barge design options

Further to the general considerations regarding the characteristics of the various barge types (see above) a more detailed analysis has been carried out, covering statutory requirements (sightlines, stability) as well as engineering aspects (construction materials, dimensions) and economic feasibility (newbuilding price).

All hydrostatic calculations (floating position under different loading conditions, stability, bending moments) have been performed with the naval architecture software Delftship, version 14.30 (http://www.delftship.net/).

It has to be noted that the barge designs have not been optimized from a hydrodynamic perspective as the focus was placed on the optimization of the cargo capacity.

4.1 Analysis of sightlines

A sufficiently unobstructed view from the wheelhouse / the helmsman's positions is essential for safety of navigation on inland waterways. For non-motorized barges the provisions of the European Standard for Technical Requirements for Inland Waterway Vessels (ES-TRIN) are not applicable as they are not equipped with a wheelhouse, however, operational limits as defined in the navigational police regulations have to be taken into account.

Most navigational police regulations for the European inland waterway network are at least based on the European Code for Inland Waterways (CEVNI) of the UNECE Inland Water Transport Committee, 6th revised edition, Geneva 2021 (https://unece.org/sites/default/files/2022-02/2109540_E_pdf_web%2BCorr1.pdf), therefore this set of rules has been used as a benchmark for the assessment of sightlines.

Article 1.07 of the CEVNI requires that the "load […] of the vessel shall not restrict the direct view at a distance of more than 350 m in front of the vessel." This means that a direct sightline from the helmsman's position to a point not farther than 350 m in front of the bow of the vessel or convoy on the surface of the water must be present.

In order to cover a realistic range of possible pusher vessels two different types which are typical for Danube navigation have been taken into consideration for the assessment of sightlines – the main difference between the two versions is that type 1 has a fixed wheelhouse while type 2 is equipped with an elevating wheelhouse which can be lifted in order to provide more favourable visibility for high cargoes.

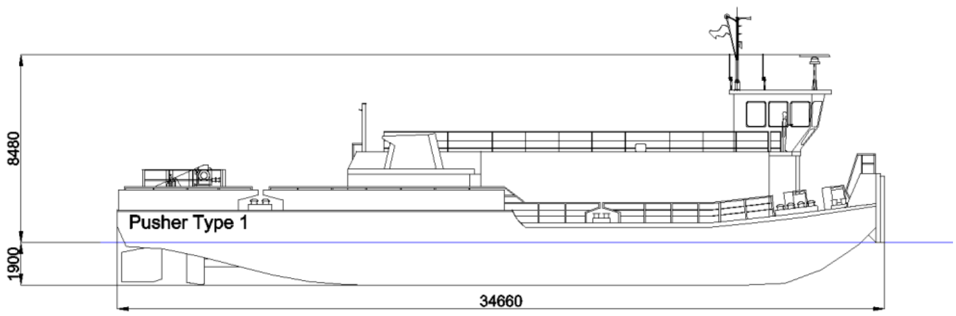

Figure 9: Pusher type 1 – fixed wheelhouse

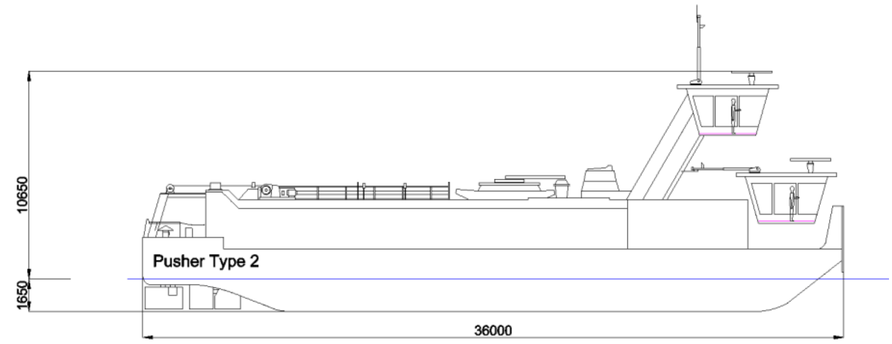

Figure 10: Pusher type 2 – elevating wheelhouse

The analysis has been carried out under the assumption that for all considered loading conditions the barges are floating on level trim and for convoy formations with only one barge length. In line with the initial thoughts on barge design has furthermore been assumed that the load consists of 45' high-cube containers, which certainly has a considerable impact on the sightlines.

The principal characteristics of the containers to be considered in the assessment have been provided by our project partner Nothegger Transport Logistik GmbH:

Length:	13,716 m
Width:	2,550 m
Height:	2,896 m
Tara:	4900 kg
max. payload:	29100 kg
max. gross weight:	34000 kg

For all combinations of pushers and barges three different loading conditions for the containers have been considered:
- all containers empty
- all containers loaded to 70% of the permissible maximum load
- all containers loaded to the maximum permissible load

The sightlines have been assessed geometrically, assuming a height of eye of 1,65 m above the wheelhouse floor at the steering position (cf. ES-TRIN 2021/1, Article 7.02 (3)).

Annex 18 – Sightlines for 001 Europa 2b barge – steel
Annex 19 – Sightlines for 001 Europa 2b barge – aluminum
Annex 20 – Sightlines for 002 Europa 3a barge – steel
Annex 21 – Sightlines for 002 Europa 3a barge – aluminum
Annex 22 – Sightlines for 003 IW-NET 3 units abreast – steel
Annex 23 – Sightlines for 003 IW-NET 3 units abreast – aluminum
Annex 24 – Sightlines for 004 IW-NET NEWS Evolution – steel
Annex 25 – Sightlines for 004 IW-NET NEWS Evolution – aluminum
Annex 26 – Sightlines for 005 IW-NET Containers transverse – steel
Annex 27 – Sightlines for 005 IW-NET Containers transverse – aluminum
Annex 28 – Sightlines for 006 IW-NET 3 units abreast long – steel
Annex 29 – Sightlines for 006 IW-NET 3 units abreast long – aluminum

Annex 30 – Sightlines for 007 IW-NET NEWS Evolution long – steel
Annex 31 – Sightlines for 007 IW-NET NEWS Evolution long – aluminum
Annex 32 – Sightlines for 008 IW-NET 3 units abreast long/shallow – steel
Annex 33 – Sightlines for 008 IW-NET 3 units abreast long/shallow – aluminum

The assessment shows that pushers with a fixed wheelhouse will in most cases not be suitable to be used for the transport of 45' high-cube containers. In general, sightlines in compliance with the applicable rules can only be demonstrated for one layer of containers. For two layers of containers compliance with the applicable rules can mainly be demonstrated for maximum load only.

Pusher Type 1 (fixed wheelhouse)						pushed convoy one barge length						
						loading condition						
						2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height		empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20								
Europa 3a	002	90,00	11,45	3,25								
IW-NET 3 units abreast	003	81,00	9,50	3,20								
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10								
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00								
IW-NET 3 units abreast long	006	94,77	9,50	3,20								
IW-NET NEWS Evolution long	007	97,32	11,45	4,10								
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20								

Table 6: Pusher type 1 (fixed wheelhouse) - sightlines assessment for steel barges

Pusher Type 1 (fixed wheelhouse)						pushed convoy one barge length						
						loading condition						
						2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height		empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20								
Europa 3a	002	90,00	11,45	3,25								
IW-NET 3 units abreast	003	81,00	9,50	3,20								
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10								
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00								
IW-NET 3 units abreast long	006	94,77	9,50	3,20								
IW-NET NEWS Evolution long	007	97,32	11,45	4,10								
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20								

Table 7: Pusher type 1 (fixed wheelhouse) - sightlines assessment for aluminum barges

For pushers with elevating wheelhouses the situation is much more favorable – two layers of containers can be carried within the applicable legal framework in all standard loading conditions assessed in this study, for three layers in most pusher/barge combinations compliance can be demonstrated for containers with 70 % of the maximum load.

Pusher Type 2 (elevating wheelhouse)						pushed convoy one barge length – loading condition							
							2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height		empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20								
Europa 3a	002	90,00	11,45	3,25								
IW-NET 3 units abreast	003	81,00	9,50	3,20								
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10								
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00								
IW-NET 3 units abreast long	006	94,77	9,50	3,20								
IW-NET NEWS Evolution long	007	97,32	11,45	4,10								
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20								

Table 8: Pusher type 2 (elevating wheelhouse) – sightlines assessment for steel barges

Pusher Type 2 (elevating wheelhouse)						pushed convoy one barge length – loading condition							
							2 layers				3 layers		
Vessel type	Project ID	length	breadth	side height		empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20								
Europa 3a	002	90,00	11,45	3,25								
IW-NET 3 units abreast	003	81,00	9,50	3,20								
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10								
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00								
IW-NET 3 units abreast long	006	94,77	9,50	3,20								
IW-NET NEWS Evolution long	007	97,32	11,45	4,10								
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20								

Table 9: Pusher type 2 (elevating wheelhouse) – sightlines assessment for aluminum barges

The situation is slightly less favorable for the aluminum-built barge versions due to the lower lightship weight and the lower draught, which increases the air-draught for any given loading condition and thus bears the risk of impairing the view from the wheelhouse. However, also for aluminum barges carrying two layers of containers is possible for all assessed loading conditions.

4.1.1 Visualisation of view from the wheelhouse – selected examples

In order to facilitate understanding of the impact of sightlines and the importance of an unobstructed view from the wheelhouse also for audiences which are less familiar with reading and interpreting technical drawings a number of situations have been created in 3D renderings. The distance of 350 m in front of the bow is marked by a red sphere in the following illustrations – if the sphere is visible above the container stack, the loading condition complies with the CEVNI requirements.

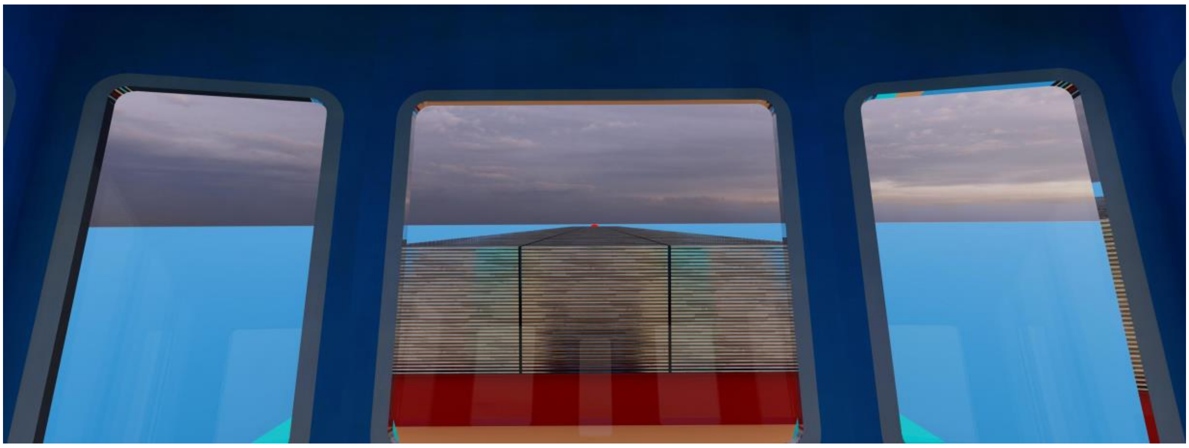

Figure 11: Pusher type 1 with barge 003 IW-NET 3 units abreast – 2 layers of empty 45' high-cube containers

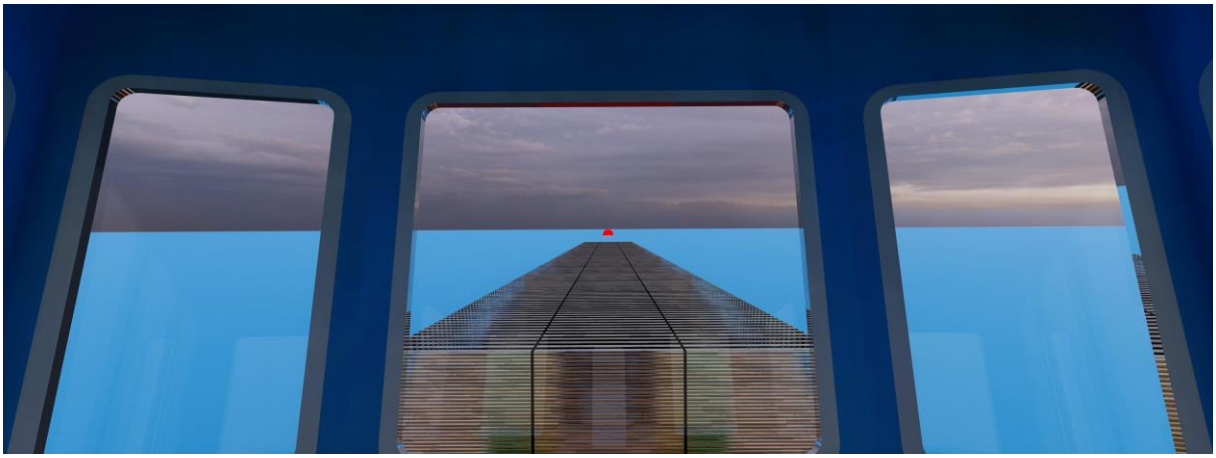

Figure 12: Pusher type 1 with barge 003 IW-NET 3 units abreast – 2 layers of 45' high-cube containers 100 % full

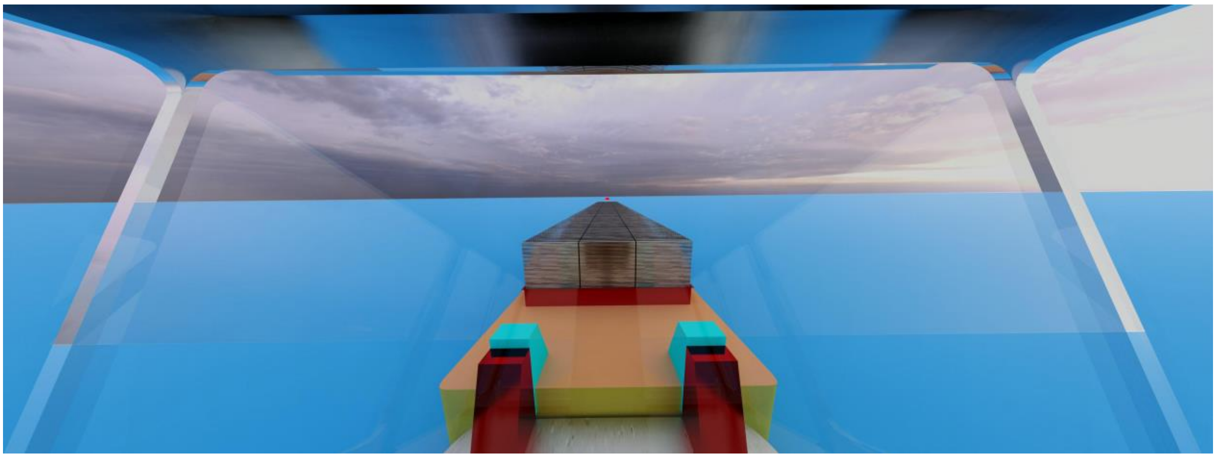

Figure 13:Pusher type 2 with barge 003 IW-NET 3 units abreast - 2 layers of empty 45' high-cube containers

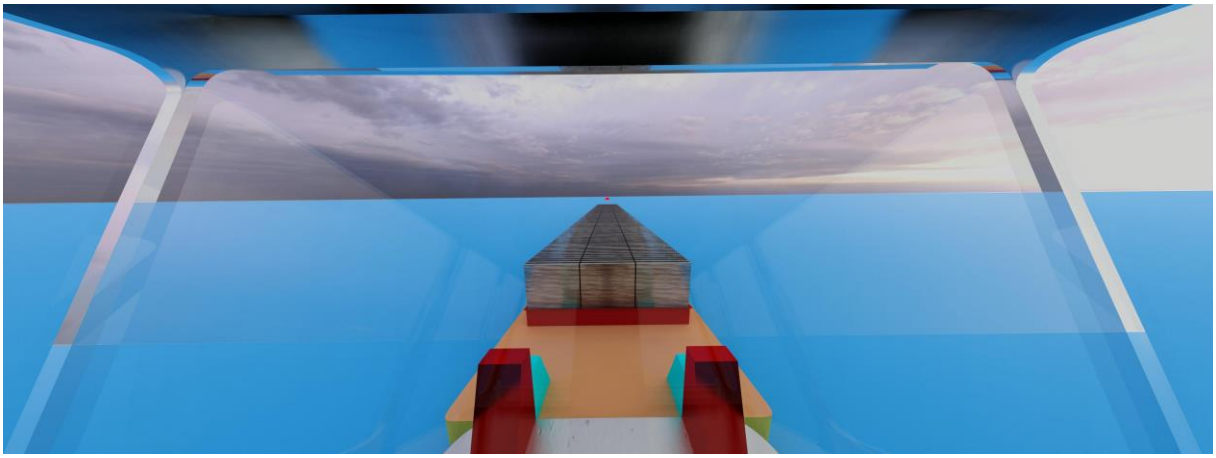

Figure 14: Pusher type 2 with barge 003 IW-NET 3 units abreast – 2 layers of 45' high-cube containers 100 % full

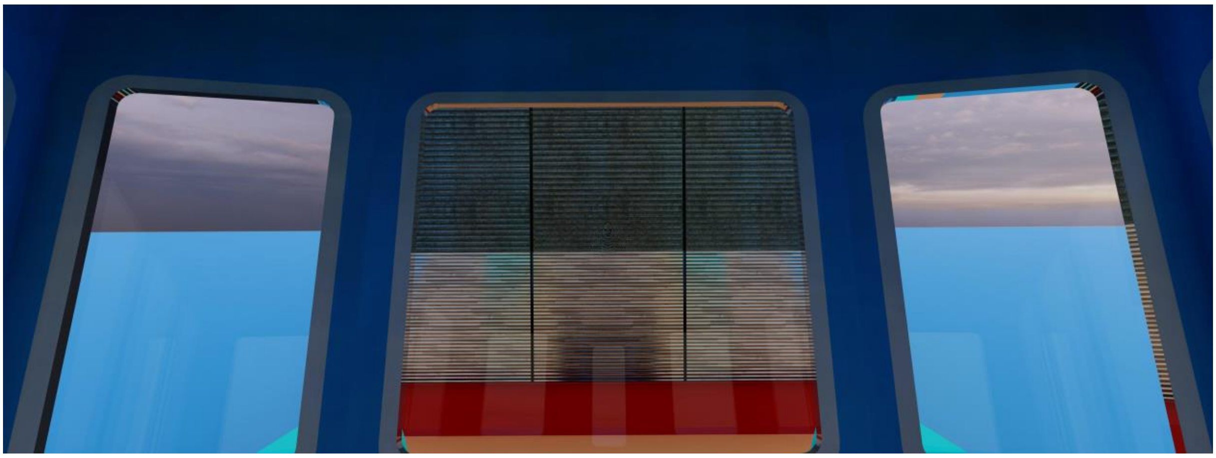

Figure 15: Pusher type 1 with barge 003 IW-NET 3 units abreast – 3 layers of empty 45' high-cube containers

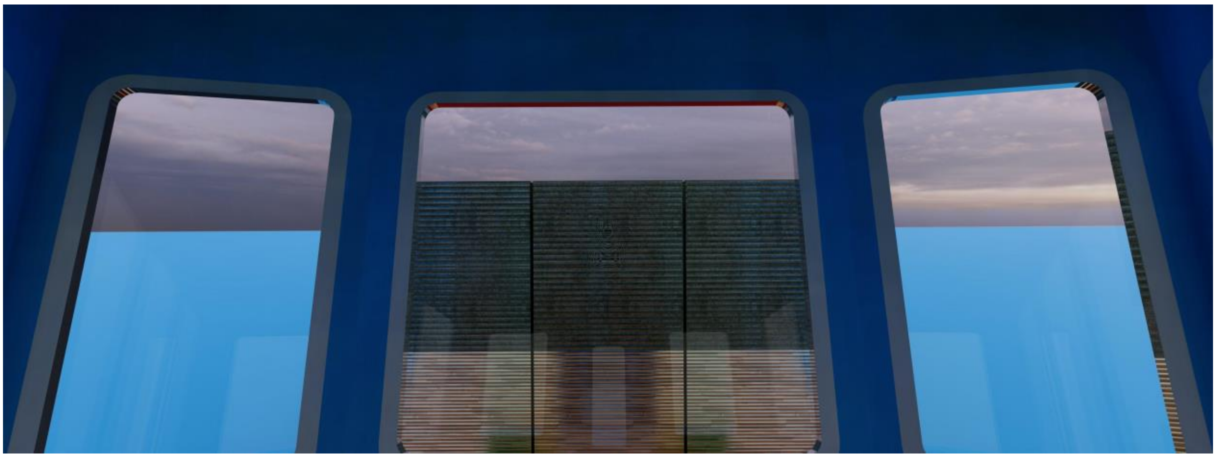

Figure 16: Pusher type 1 with barge 003 IW-NET 3 units abreast – 3 layers of 45' high-cube containers 100 % full

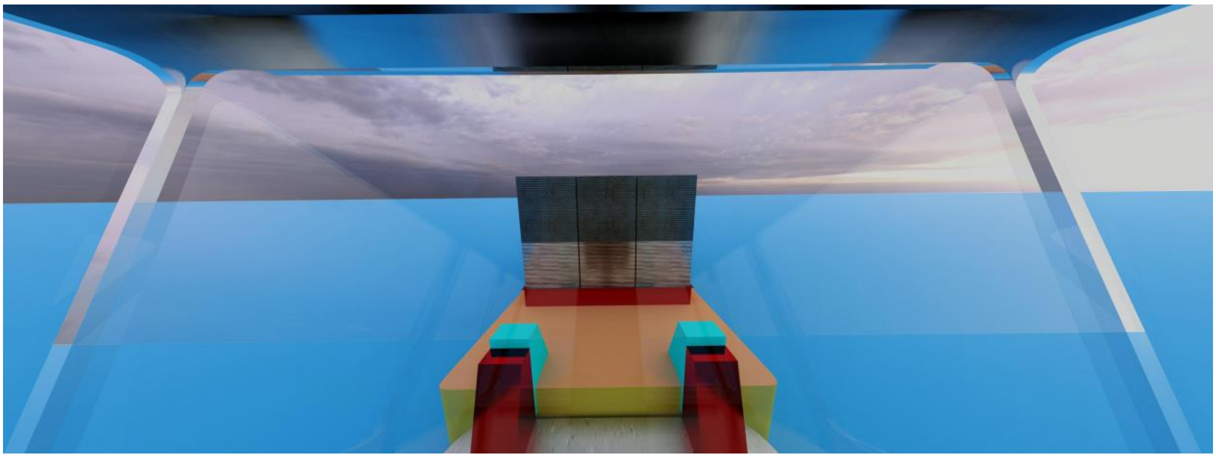

Figure 17: Pusher type 2 with barge 003 IW-NET 3 units abreast – 3 layers of empty 45' high-cube containers

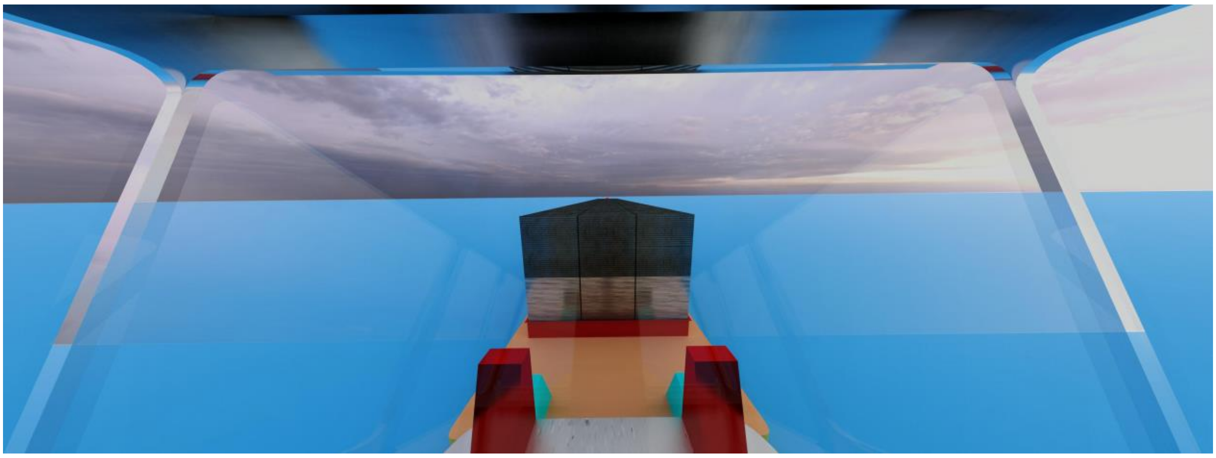

Figure 18: Pusher type 2 with barge 003 IW-NET 3 units abreast – 3 layers of 45' high-cube containers 100 % full

Figure 19: Pusher type 1 with barge 007 IW-NET NEWS Evolution long – 2 layers of empty 45' high-cube containers

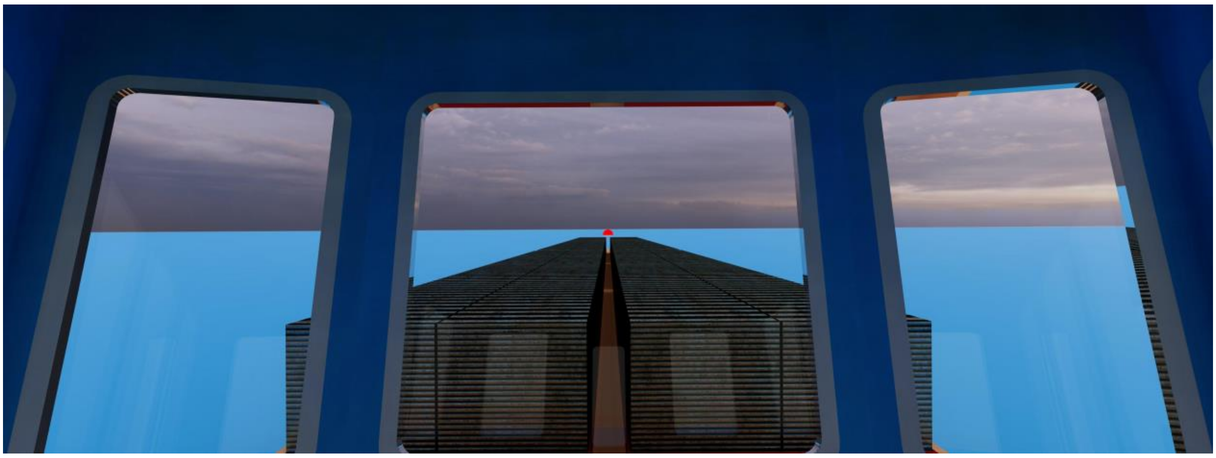

Figure 20: Pusher type 1 with barge 007 IW-NET NEWS Evolution long – 2 layers of 45' high-cube containers 100 % full

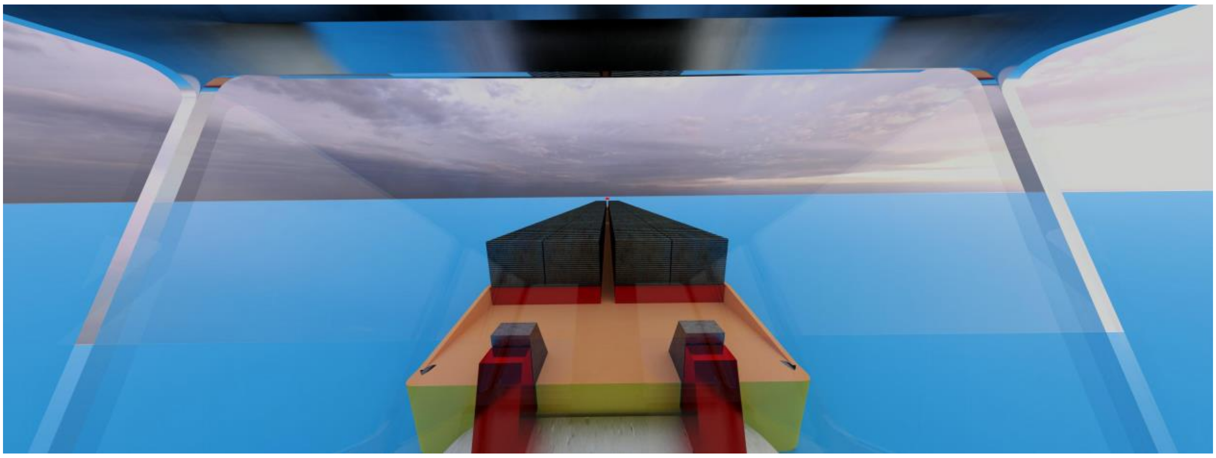

Figure 21: Pusher type 2 with barge 007 IW-NET NEWS Evolution long – 2 layers of empty 45' high-cube containers

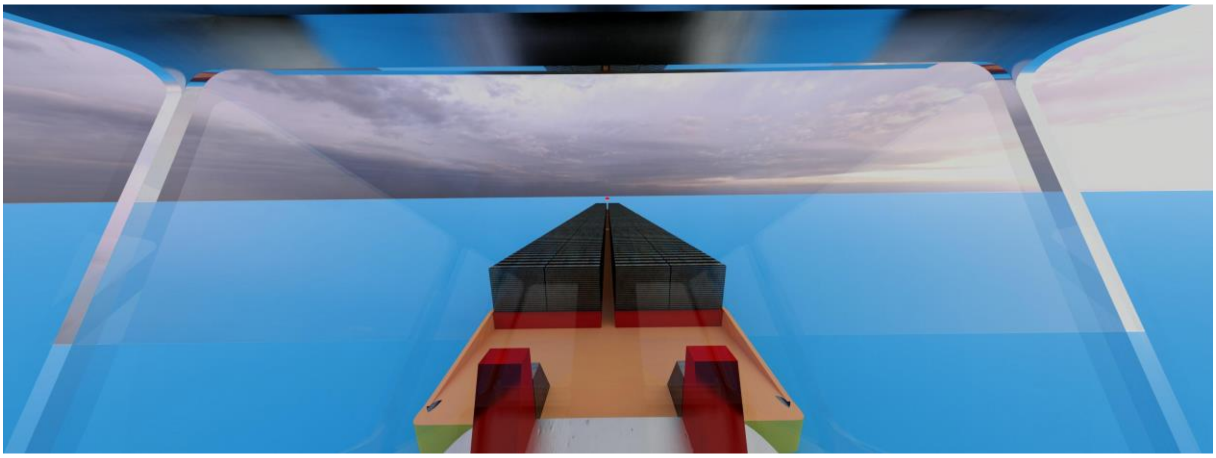

Figure 22: Pusher type 2 with barge 007 IW-NET NEWS Evolution long – 2 layers of empty 45' high-cube containers

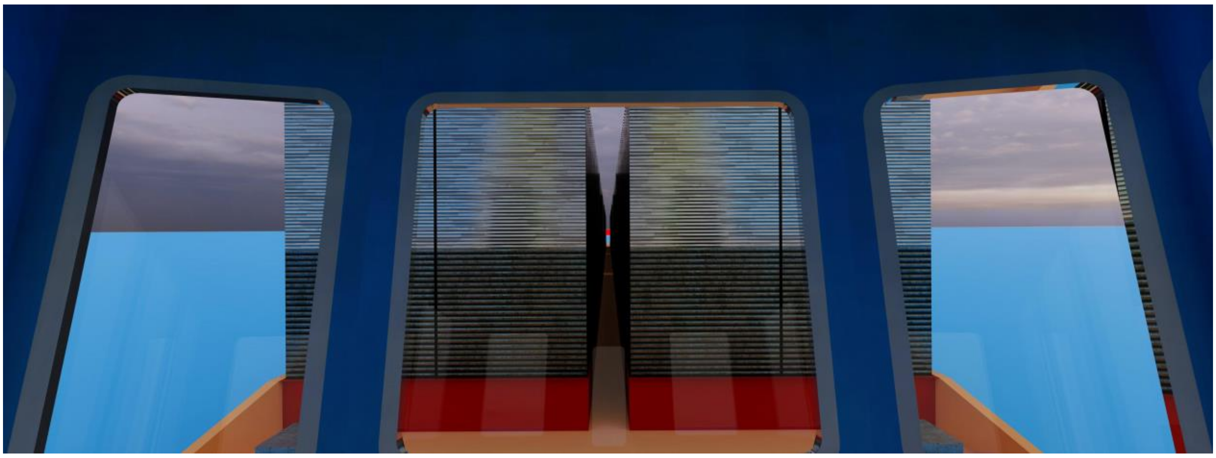

Figure 23: Pusher type 1 with barge 007 IW-NET NEWS Evolution long – 3 layers of empty 45’ high-cube containers

Figure 24: Pusher type 1 with barge 007 IW-NET NEWS Evolution long – 2 layers of 45’ high-cube containers 100 % full

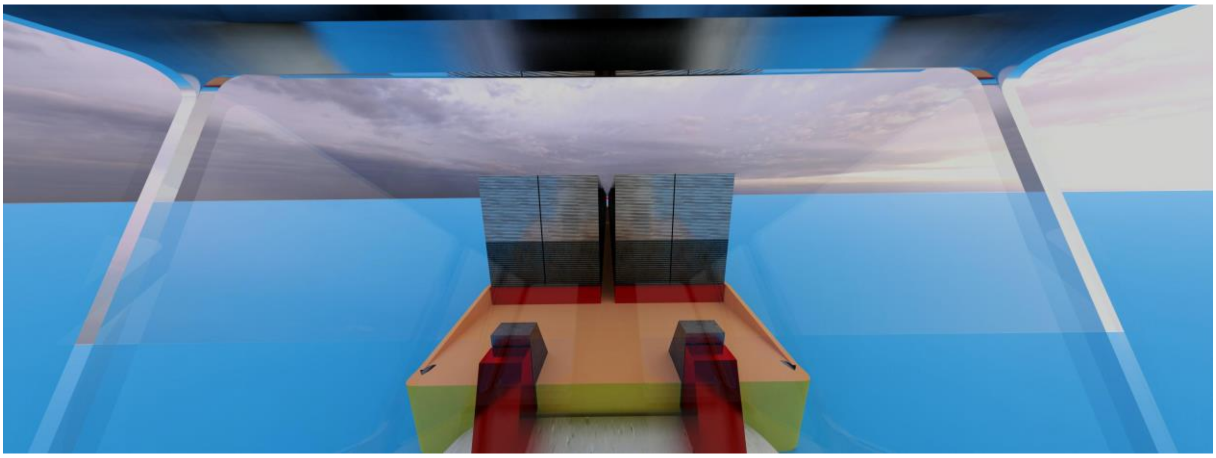

Figure 25: Pusher type 2 with barge 007 IW-NET NEWS Evolution long – 3 layers of empty 45’ high-cube containers

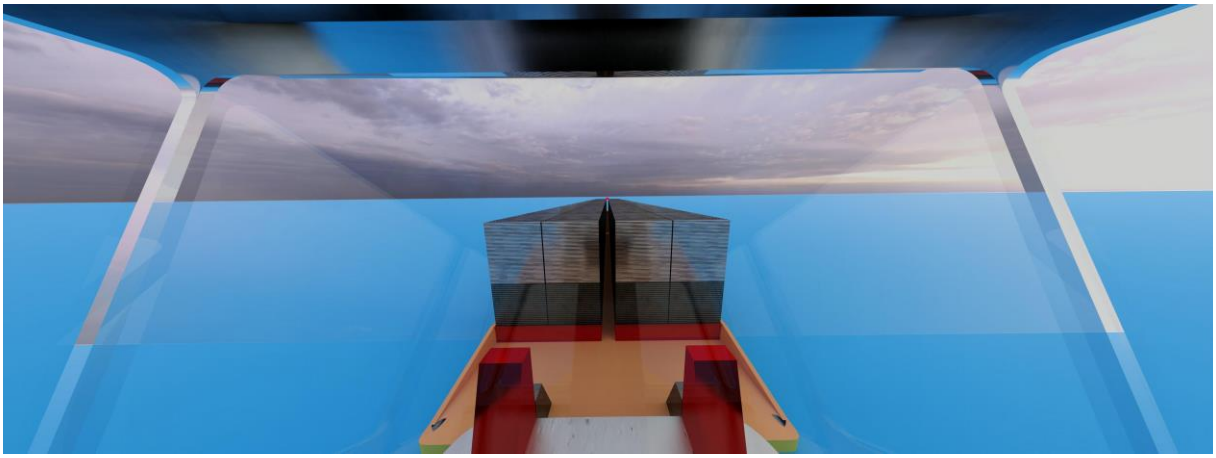

Figure 26: Pusher type 2 with barge 007 IW-NET NEWS Evolution long – 2 layers of 45' high-cube containers 100 % full

4.2 Stability analysis

Both, technical requirements (ES-TRIN) and navigational police regulations (CEVNI) address the issue of stability of inland navigation vessels carrying containers.

The provisions of Article 1.07 No. 5 of CEVNI focus on the individual operational situation and require a stability check prior to loading and unloading as well as prior to departure. The responsibility for such stability checks lies with the boat master. Exemptions from performing stability checks apply to certain loading configurations which are always deemed inherently stable.

5. The stability of vessels carrying containers shall be ensured at any time. The boatmaster shall prove that the stability check has been made before starting loading and unloading, as well as before departure.

   The results of the stability check and the actual loading plan shall be kept on board and shall be available at any moment. In addition, vessels shall keep on board the documents related to the stability required by the competent authority.

   The check of stability is not required for vessels carrying containers, if a vessel can be loaded across its breadth:

   (a) With maximum three rows of containers and it is loaded with not more than one tier of containers beginning from the bottom of the hold; or

   (b) With four or more rows of containers and it is loaded solely with not more than two tiers of containers beginning from the bottom of the hold.

With regard to the technical characteristics of an inland navigation vessel the ES-TRIN sets out a range of provisions in Chapter 27 concerning limit conditions and methods of calculation for the transport of non-secured and secured containers, taking into account the hydrostatic characteristics of the hull (mainly depending on the shape of the hull and the weight distribution), the loading situation and the heeling moments to be considered.

Annex 34 – Wind silhouettes 001 Europa 2b barge
Annex 35 – Wind silhouettes 002 Europa 3a barge
Annex 36 – Wind silhouettes 003 IW-NET 3 units abreast
Annex 37 – Wind silhouettes 004 IW-NET NEWS Evolution
Annex 38 – Wind silhouettes 005 IW-NET Containers transverse
Annex 39 – Wind silhouettes 006 IW-NET 3 units abreast long
Annex 40 – Wind silhouettes 007 IW-NET NEWS Evolution long
Annex 41 – Wind silhouettes 008 IW-NET 3 units abreast long/shallow

Annex 42 – Heeling moments 001 Europa 2b barge
Annex 43 – Heeling moments 002 Europa 3a barge
Annex 44 – Heeling moments 003 IW-NET 3 units abreast
Annex 45 – Heeling moments 004 IW-NET NEWS Evolution
Annex 46 – Heeling moments 005 IW-NET Containers transverse
Annex 47 – Heeling moments 006 IW-NET 3 units abreast long
Annex 48 – Heeling moments 007 IW-NET NEWS Evolution long
Annex 49 – Heeling moments 008 IW-NET 3 units long/shallow

For the purpose of this project, it was decided to assess the stability of the different barge designs under the conditions set out in Article 27.02 of ES-TRIN (non-secured containers) and for six standard loading conditions:

- 2 layers of 45' high-cube containers empty.
- 2 layers of 45' high-cube containers 70 % full
- 2 layers of 45' high-cube containers 100 % full
- 3 layers of 45' high-cube containers empty.
- 3 layers of 45' high-cube containers 70 % full
- 3 layers of 45' high-cube containers 100 % full

For each loading condition the calculation delivers a maximum allowable vertical center of gravity (VCG) that has to be met in order to ensure compliance with the requirements of Article 27.02 of ES-TRIN. The actual VCG of each loading condition is assessed against the maximum allowable VCG.

It can be shown that most of the loading conditions comply with the statutory requirements, the only exceptions being the 9,50 m wide barge versions in the short and long variants for 3 layers of loaded containers (70 % and 100 %) and the long version of the NEWS Evolution barge for 3 layers of fully loaded containers.

Annex 50 – Stability calculation 001 Europa 2b barge
Annex 51 – Stability calculation 002 Europa 3a barge
Annex 52 – Stability calculation 003 IW-NET 3 units abreast
Annex 53 – Stability calculation 004 IW-NET NEWS Evolution
Annex 54 – Stability calculation 005 IW-NET Containers transverse
Annex 55 – Stability calculation 006 IW-NET 3 units abreast long
Annex 56 – Stability calculation 007 IW-NET NEWS Evolution long
Annex 57 – Stability calculation 008 IW-NET 3 units abreast long/shallow

Stability assessment - Position of actual VCG vs. Maximum allowable VCG - steel					loading condition						
						2 layers				3 layers	
Vessel type	Project ID	length	breadth	side height	empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20							
Europa 3a	002	90,00	11,45	3,25							
IW-NET 3 units abreast	003	81,00	9,50	3,20							
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10							
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00							
IW-NET 3 units abreast long	006	94,77	9,50	3,20							
IW-NET NEWS Evolution long	007	97,32	11,45	4,10							
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20							

Table 10: Stability assessment for steel barges

Stability assessment - Position of actual VCG vs. Maximum allowable VCG - aluminium					loading condition						
						2 layers				3 layers	
Vessel type	Project ID	length	breadth	side height	empty	70 % full	100 % full		empty	70 % full	100 % full
Europa 2b	001	76,50	11,45	3,20							
Europa 3a	002	90,00	11,45	3,25							
IW-NET 3 units abreast	003	81,00	9,50	3,20							
IW-NET NEWS Evolution v2	004_v2	85,92	11,45	4,10							
IW-NET Containers transverse v2 (Solidworks)	005_v2	89,80	16,28	4,00							
IW-NET 3 units abreast long	006	94,77	9,50	3,20							
IW-NET NEWS Evolution long	007	97,32	11,45	4,10							
IW-NET 3 units abreast long/shallow	008	94,77	11,45	3,20							

Table 11: Stability assessment for aluminum barges

The difference between barges built from grade A shipbuilding steel and from aluminium is rather insignificant, just the loading case of 3 layers of full containers for the long version of the NEWS Evolution barge changes from negative to positive for the aluminium version due to less draught and consequently more residual freeboard.

4.3 Analysis of different construction materials

In general, inland navigation vessels are built from “grade A” shipbuilding steel. For special applications (e.g. passenger vessels, high-speed vessels, patrol vessels) other materials can be feasible (e.g. aluminum, fiber-reinforced plastics).

4.3.1 General characteristics of construction materials

4.3.1.1 *Grade A shipbuilding steel*

- cost-efficient
- robust
- easy to repair.
- ductile (meaning that the material can be significantly deformed before breaking)
- relatively heavy
- material recycling possible.
- energy input for production of 1 t raw steel ca. 18 GJ

4.3.1.2 *Aluminium*

- expensive
- lightweight
- less ductile than shipbuilding steel (therefore higher tendency to spring a leak in case of an impact (e.g., grounding, collision))
- building and repair require higher expertise than steel, therefore not everywhere available.
- material recycling possible.
- energy input for production of 1 t raw aluminum ca. 124 GJ

4.3.1.3 *Composites (e.g., GRP (glass-fibre reinforced plastics), carbon etc.)*

- (extremely) expensive, cost factor mainly depending on fibre material (e.g. glass vs. carbon)
- even lighter than aluminum
- extremely strong, but brittle → virtually no deformation before sudden breaking
- building and repair in general require special expertise and controlled climate (e.g. minimum temperature for curing resins)
- scratches on the surface enable ingress of water into the matrix, weakening the material.
- material recycling, in particular separation of fibers and resin, currently not possible

With a view to the general characteristics of the mentioned construction materials it can be concluded that composites are (at least not yet) technically and economically feasible for cargo vessels in inland navigation and can therefore be disregarded for further consideration within the framework of this project.

4.3.2 Methodology for assessment of longitudinal strength

To achieve acceptably comparable results, the preliminary dimensioning for all barge versions has been carried out using the software GLRulesND (Version 2.950, Edition 2014). Based on the preliminary results for the thickness of bottom, bilge, and side plating as well as dimensions of bottom and side girders the main sections for all barge versions have been drawn up. The structural design has been further refined by assessing the individual moments of inertia and section moduli of the cross sections of the different barge versions against the bending moments resulting from a standardised load distribution at a draught of 2,70 m. The structural design has been carried out for all barge version for grade A shipbuilding steel as well as for aluminum.

Annex 58 – section plan 001 Europa 2b barge – steel
Annex 59 – section plan 001 Europa 2b barge – aluminium
Annex 60 – section plan 002 Europa 3a barge – steel
Annex 61 – section plan 002 Europa 3a barge – aluminium
Annex 62 – section plan 003 IW-NET 3 units abreast – steel
Annex 63 – section plan 003 IW-NET 3 units abreast – aluminium
Annex 64 – section plan 004 IW-NET NEWS Evolution – steel
Annex 65 – section plan 004 IW-NET NEWS Evolution – aluminium
Annex 66 – section plan 005 IW-NET Containers transverse – steel
Annex 67 – section plan 005 IW-NET Containers transverse – aluminium

Annex 68 – section plan 006 IW-NET 3 units abreast long – steel
Annex 69 – section plan 006 IW-NET 3 units abreast long – aluminium
Annex 70 – section plan 007 IW-NET NEWS Evolution long – steel
Annex 71 – section plan 007 IW-NET NEWS Evolution long – aluminium
Annex 72 – section plan 008 IW-NET 3 units abreast long/shallow – steel
Annex 73 – section plan 008 IW-NET 3 units abreast long/shallow - aluminium

The standard load distribution has been defined as a load of the maximum deadweight of each individual barge at a draught of 2,70 m, evenly distributed over 70% of the length of the cargo hold (respectively of the distance between the foremost and the rearmost cargo hold bulkhead for barge types with more than one cargo hold).

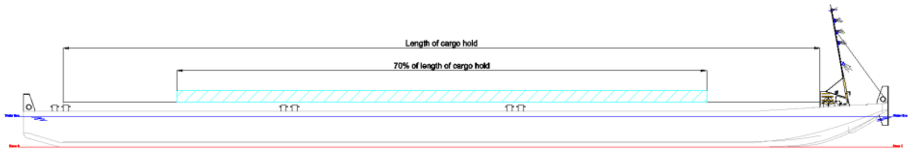

Figure 27: Principal sketch of standardised load distribution

Corresponding loading conditions have been set up in the naval architecture software DelftShip for each barge version in order to calculate the individual benchmark bending moments.

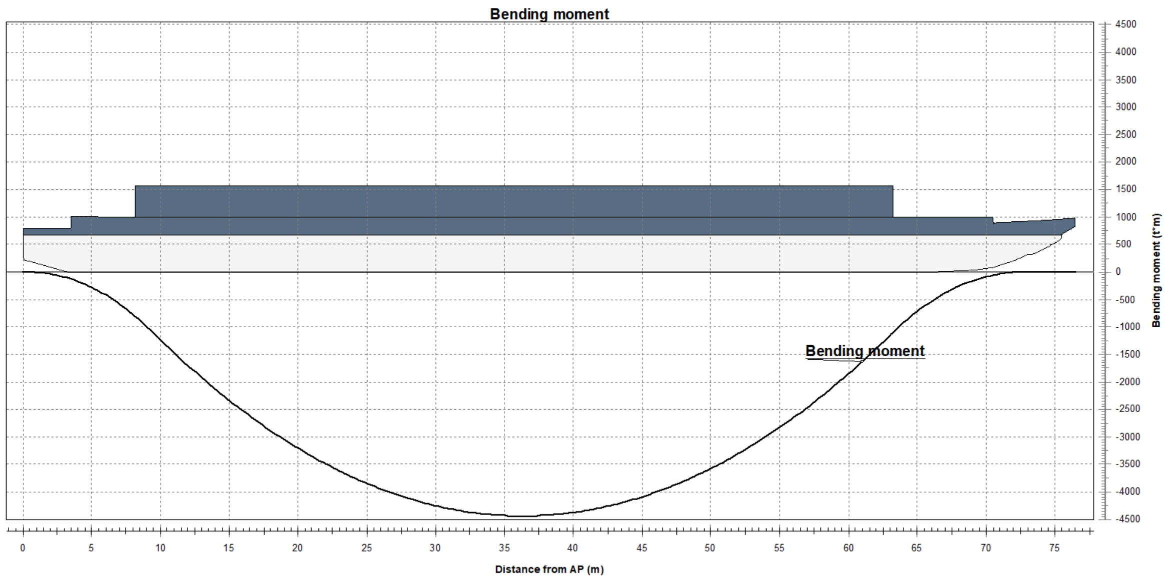

Figure 28: Example of bending moment diagram

Annex 74 – Bending moment 001 Europa 2b barge
Annex 75 – Bending moment 002 Europa 3a barge
Annex 76 – Bending moment 003 IW-NET 3 units abreast
Annex 77 – Bending moment 004 IW-NET NEWS Evolution
Annex 78 – Bending moment 005 IW-NET Containers transverse
Annex 79 – Bending moment 006 IW-NET 3 units abreast long
Annex 80 – Bending moment 007 IW-NET NEWS Evolution long
Annex 81 – Bending moment 008 IW-NET 3 units abreast long/shallow

With a view to as far as possible achieve directly comparable results for lightship weights and draughts at different loading conditions of the various barge versions for different building materials we endeavoured to keep the safety factor between the maximum permissible bending moment and the actually given bending moment in a range between 2,15 and 2,3.

Annex 82 – Moment of inertia/section modulus 001 Europa 2b barge
Annex 83 – Moment of inertia/section modulus 002 Europa 3a barge
Annex 84 – Moment of inertia/section modulus 003 IW-NET 3 units abreast
Annex 85 – Moment of inertia/section modulus 004 IW-NET NEWS Evolution
Annex 86 – Moment of inertia/section modulus 005 IW-NET Containers transverse
Annex 87 – Moment of inertia/section modulus 006 IW-NET 3 units abreast long
Annex 88 – Moment of inertia/section modulus 007 IW-NET NEWS Evolution long
Annex 89 – Moment of inertia/section modulus 008 IW-NET 3 units abreast long/shallow

It has to be noted that an individual structural optimization of the different barge designs would most certainly lead to different results, however, with a view to a valid comparison of different building materials it was decided to favor comparability over individual optimization.

4.3.3 Methodology for estimation of lightship weights

The calculations of the moments of inertia of the barge designs have been performed in such a way that a distinction between plate material (e.g. side plating, bottom plating etc.) and girder material could be displayed. This method permits to calculate a frame factor as the relation between the sum of the cross-section areas of the plate elements and the sum of the cross-section areas of the girder elements. A general uncertainty allowance of 0,10 has been added to the calculated frame factor.

From the Delftship-3D-CAD models the surface areas of the different regions (side, bottom, bilge etc.) have been extracted and the material volume of the plate material has been calculated using the respective plate thicknesses resulting from the structural design of the main sections.

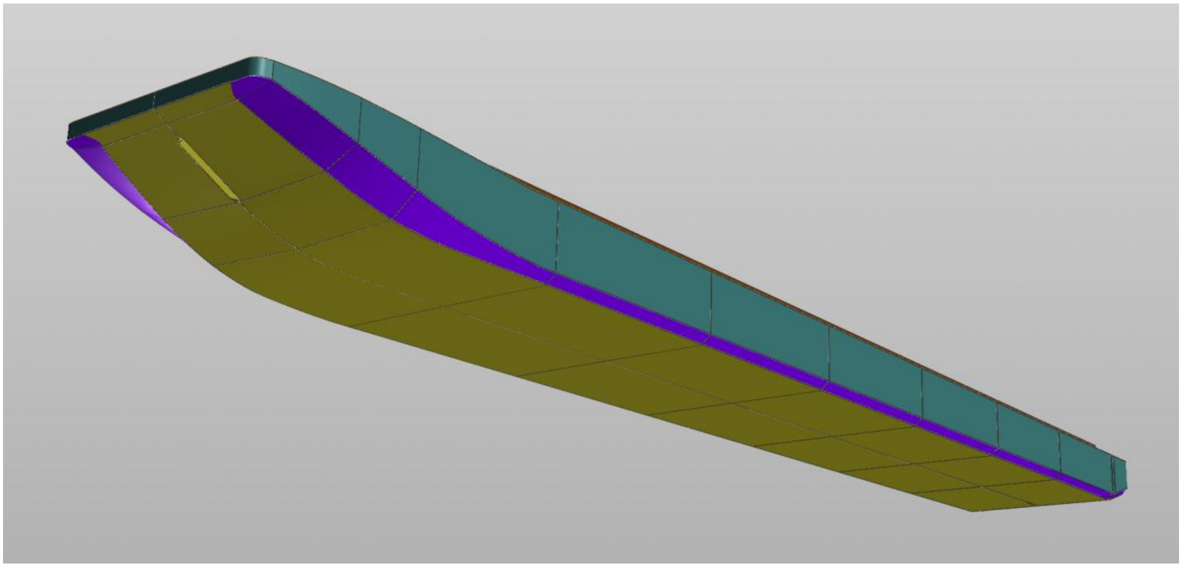

Figure 29: Layer definition in DelftShip – view 1

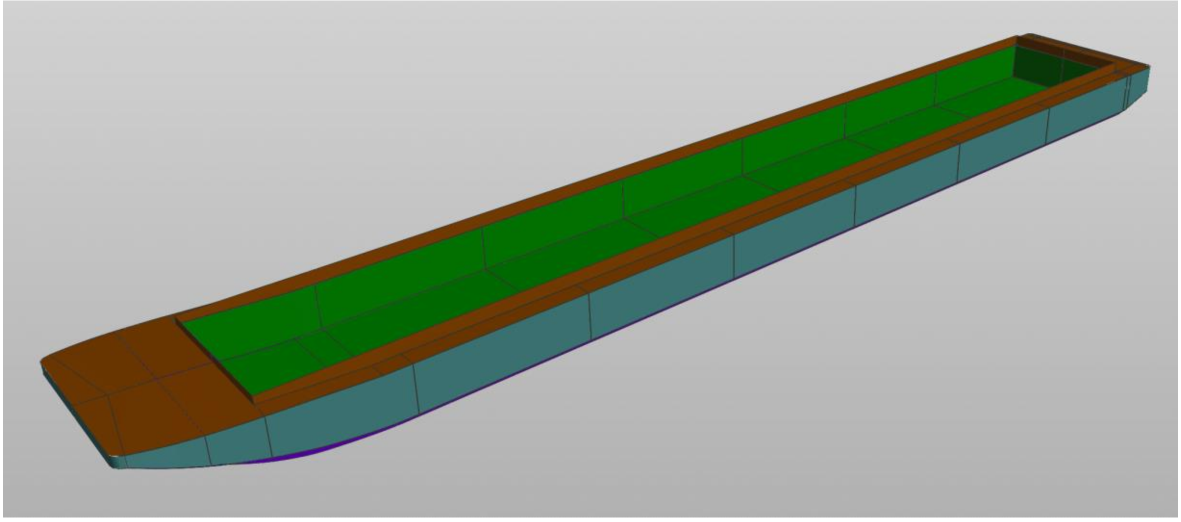

Figure 30: Layer definition in DelftShip – view 2

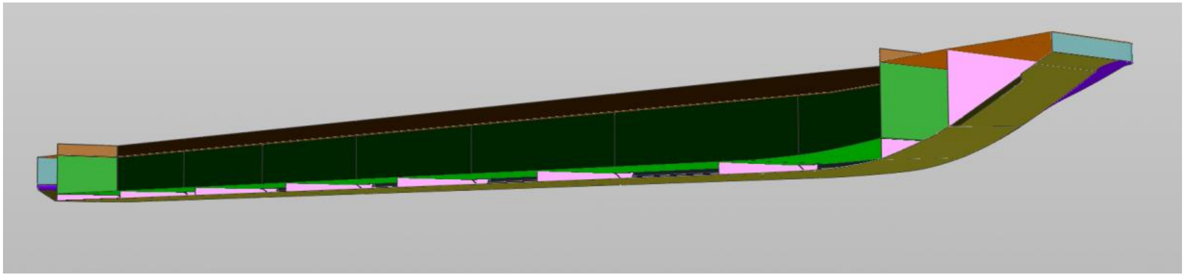

Figure 31: Layer definition in DelftShip – view 3

Layer properties

Description	Visible	Symmetric	Color	Density	Thickness	Area	Weight	LCG	TCG	VCG
					m	m²	t	m	m	m
Bottom	YES	YES		0,0000	0,000	798,20	0,000	37,830	0,000 (CL)	0,142
Side	YES	YES		0,0000	0,000	432,95	0,000	35,516	0,000 (CL)	1,914
Bilge	YES	YES		0,0000	0,000	112,43	0,000	41,740	0,000 (CL)	0,635
Deck	YES	YES		0,0000	0,000	259,64	0,000	40,811	0,000 (CL)	3,341
Hatch coaming	YES	YES		0,0000	0,000	116,83	0,000	35,591	0,000 (CL)	3,611
Cargo hold	YES	YES		0,0000	0,000	409,57	0,000	36,864	0,000 (CL)	1,887
Double bottom	YES	YES		0,0000	0,000	613,89	0,000	37,030	0,000 (CL)	0,515
Bulkheads	YES	YES		0,0000	0,000	118,46	0,000	45,374	0,000 (CL)	1,451
Binnencontainer 45 ft wecon	NO	NO		0,0000	0,000	3939,94	0,000	35,690	0,000 (CL)	3,400
Binnencontainer 45 ft wecon 3rd layer	NO	NO		0,0000	0,000	1969,97	0,000	35,690	0,000 (CL)	7,748

Figure 32: Example for layer properties in DelftShip

The weight of the casco construction has then been derived by applying the frame factor. To obtain the final lightship weight an allowance for equipment (bollards, winches) and the weight of anchors and anchor chains in accordance with the requirements of Article 13.01 of ES-TRIN 2021/1 have been added.

Annex 90 – Delftship layer properties 001 Europa 2b barge
Annex 91 – Delftship layer properties 002 Europa 3a barge
Annex 92 – Delftship layer properties 003 IW-NET 3 units abreast
Annex 93 – Delftship layer properties 004 IW-NET NEWS Evolution
Annex 94 – Delftship layer properties 005 IW-NET Containers transverse
Annex 95 – Delftship layer properties 006 IW-NET 3 units abreast long
Annex 96 – Delftship layer properties 007 IW-NET NEWS Evolution long
Annex 97 – Delftship layer properties 008 IW-NET 3 units abreast long/shallow

Annex 98 – Weight estimation aluminum – same longitudinal strength
Annex 99 – Weight estimation aluminum – same plate thickness
Annex 100 – Weight estimation steel

4.3.4 Material properties

For the purpose of comparison between different construction materials the following material characteristics have been applied:

4.3.4.1 *Grade A shipbuilding steel*

Relative density: 7,8 t/m³
Yield strength:235 N/mm²

Source e.g.: http://de.coldrolledsteels.com/shipbuilding-steel-plate/bv-grade-a-shipbuilding-steel-length-3000mm.html

4.3.4.2 *Aluminium Al Mg 4,5 Mn*

Relative density: 2,66 t/m³
Yield strength:115 N/mm²

Source e.g.: https://www.alu-messing-shop.de/werkstoffinformationen

The use of aluminum as construction material for inland navigation barges is sometimes championed as a “flagship”-idea for “adapting vessels to the rivers” instead of vice versa with the notion that the specific weight of aluminum is only about a third of the specific weight of steel. In somewhat simplified and superficial discussions it is frequently disregarded that aluminum only has about half the yield strength of grade A shipbuilding steel. For demonstration purposes within this project the lightship weight for aluminum has therefore been calculated in two variants – once for identical dimensions (plate thickness, girders) as for the steel version and once for the same longitudinal strength as the steel version.

4.3.4.3 *High tensile steel*

As an alternative to aluminum alloys the option of using high tensile steel for the girder material has also been considered with a view to reducing the lightship weight of the barges.

Relative density: 7,8 t/m³
Yield strength:355 N/mm² or 460 N/mm²

The high tensile steel option has only been calculated for the 004 IW-NET NEWS Evolution barge version.

4.3.5 Comparison of lightship weights

The following table shows the lightship weights of the different barge versions calculated in application of the methodology described above:

Barge version	Lightship weight steel [t]	*Lightship weight aluminum [t] same dimensions as steel*	Lightship weight aluminum [t] same longitudinal strength as steel
001 Europa 2b	215,422	*77,118*	153,234
002 Europa 3a	333,001	*117,440*	239,923
003 IW-NET 3 units abreast	274,925	*95,297*	191,876
004 IW-NET NEWS Evolution	401,565	*137,416*	285,024
005 IW-NET Containers transverse	540,180	*189,659*	388,760
006 IW-NET 3 units abreast long	363,354	*125,144*	260,590
007 IW-NET NEWS Evolution long	488,527	*167,399*	345,474
008 IW-NET 3 units abreast long/shallow	479,919	*164,921*	336,666

Table 12: Lightship weights of the different barge versions

CAUTION: The lightship weights indicated for aluminum with the same dimensions as steel are only given for demonstration purposes. The longitudinal strength of such constructions is inadequate and not suitable for practical application.

4.3.6 Comparison of building costs

The building costs for the different barge versions have been estimated by IW-NET project partner NAVROM Shipyard SRL in February 2023. Given the volatile market situation it has been decided to display no absolute costs but only relative costs in comparison with the 001 Europa 2b barge version in grade A shipbuilding steel as a benchmark.

Relative building costs – Europa 2b = 100			
Barge version	Building costs steel	Building costs aluminum	Building costs aluminum vs. steel
001 Europa 2b	100	167	167
002 Europa 3a	151	256	170
003 IW-NET 3 units abreast	126	207	164
004 IW-NET NEWS Evolution	180	303	168
005 IW-NET Containers transverse	242	410	169
006 IW-NET 3 units abreast long	164	278	170
007 IW-NET NEWS Evolution long	218	366	168
008 IW-NET 3 units abreast long/shallow	214	356	166

Table 13: Comparison of building costs of barges

This comparison shows that based on the price levels in February 2023 an aluminum barge would cost approximately 70 % more than a steel barge.

4.3.7 Comparison of container carrying capacity

The different barge versions can be directly compared by their capacity to carry 45’ high cube containers:

Barge version	No. of 45’ high cube containers 2 layers	No. of 45’ high cube containers 3 layers
001 Europa 2b	24	36
002 Europa 3a	30	45
003 IW-NET 3 units abreast	30	45
004 IW-NET NEWS Evolution	40	60
005 IW-NET Containers transverse	60	90
006 IW-NET 3 units abreast long	36	54
007 IW-NET NEWS Evolution long	48	72
008 IW-NET 3 units abreast long/shallow	36	54

Table 14: Comparison of container carrying capacity (in no. of 45’high cube containers)

Relative container carrying capacity – Europa 2b = 100	
Barge version	
001 Europa 2b	100
002 Europa 3a	125
003 IW-NET 3 units abreast	125
004 IW-NET NEWS Evolution	167
005 IW-NET Containers transverse	250
006 IW-NET 3 units abreast long	150
007 IW-NET NEWS Evolution long	200
008 IW-NET 3 units abreast long/shallow	150

Table 15: Comparison of relative container carrying capacity

However, the usual benchmark for indicating the container carrying capacity of vessels is the TEU (twenty feet equivalent unit). The capacity of the different barge designs in relation to TEU is presented below:

Barge version	Approx. TEU 2 layers	Approx. TEU 3 layers
001 Europa 2b	60	90
002 Europa 3a	72	108
003 IW-NET 3 units abreast	66	99
004 IW-NET NEWS Evolution	80	120
005 IW-NET Containers transverse	120	180
006 IW-NET 3 units abreast long	78	117
007 IW-NET NEWS Evolution long	96	144
008 IW-NET 3 units abreast long/shallow	78	117

Table 16: Comparison of container carrying capacity (in TEU)

With a view to adaptation to low-water conditions the different barge versions can also be compared by their specific draught, meaning the increase of draught per container. This comparison has been carried out for 2 and 3 layers of containers and for empty containers, containers loaded to 70 % of their capacity and containers loaded to 100 % of their capacity.

Barge version	Specific draught [mm]		
	empty	70% full	full
001 Europa 2b	6	32	42
002 Europa 3a	5	26	35
003 IW-NET 3 units abreast	7	34	46
004 IW-NET NEWS Evolution	5	26	35
005 IW-NET Containers transverse	4	18	24
006 IW-NET 3 units abreast long	6	29	39
007 IW-NET NEWS Evolution long	5	23	31
008 IW-NET 3 units abreast long/shallow	5	24	32

Table 17: Comparison of container carrying capacity by their specific draught.

4.3.8 Comparison of building costs and container carrying capacity

The relation between building costs and container carrying capacity shall in essence answer the question of which barge version has the lowest building costs per container.

	Relative costs vs. container carrying capacity	
Barge version	Steel	aluminum
001 Europa 2b	100,00	166,72
002 Europa 3a	120,53	205,09
003 IW-NET 3 units abreast	100,51	165,34
004 IW-NET NEWS Evolution	108,12	181,80
005 IW-NET Containers transverse	96,69	164,11
006 IW-NET 3 units abreast long	109,16	185,15
007 IW-NET NEWS Evolution long	108,84	182,75
008 IW-NET 3 units abreast long/shallow	142,64	237,60

Table 18: Comparison of building costs and container carrying capacity.

4.3.9 Influence of market environment

The market environment in the project period has been highly volatile, due to multiple crises (in particular Covid 19 pandemic and war in Ukraine), making a reliable estimation of concrete building costs for the different barge designs extremely difficult.
Prices for raw materials as well as for energy and other commodities necessary for shipbuilding have seen considerable ups and downs during the project period.

It is particularly interesting to note that the relation between average total building costs per kg lightship weight for grade A shipbuilding steel and aluminum has considerably decreased from approx. 3,5 in March 2021 to approx. 2,4 in January 2023. The total building costs include costs for material, wages, energy, taxes etc.
This is significant insofar, as the relation between building costs now seems to deviate from a long-term rule of thumb, saying that building in aluminum is about 3 to 4 times more expensive than building in steel. It is, however, not probable that this change would render building

in aluminum economically feasible for non-motorised cargo barges, but it could have a certain impact on other types of craft.

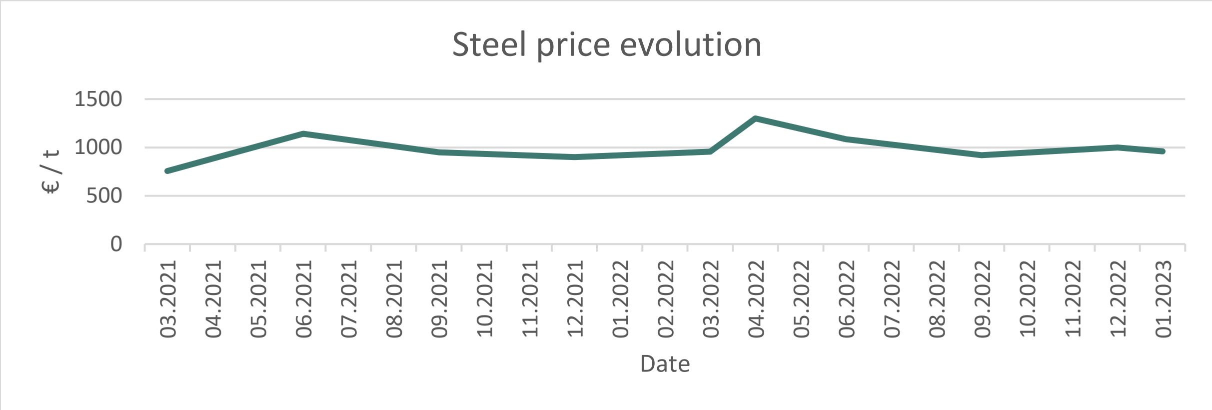

Figure 33: Steel price evolution chart (source: S.C. NAVROM Shipyard S.R.L.Galati / Arcelor Mittal Distribution)

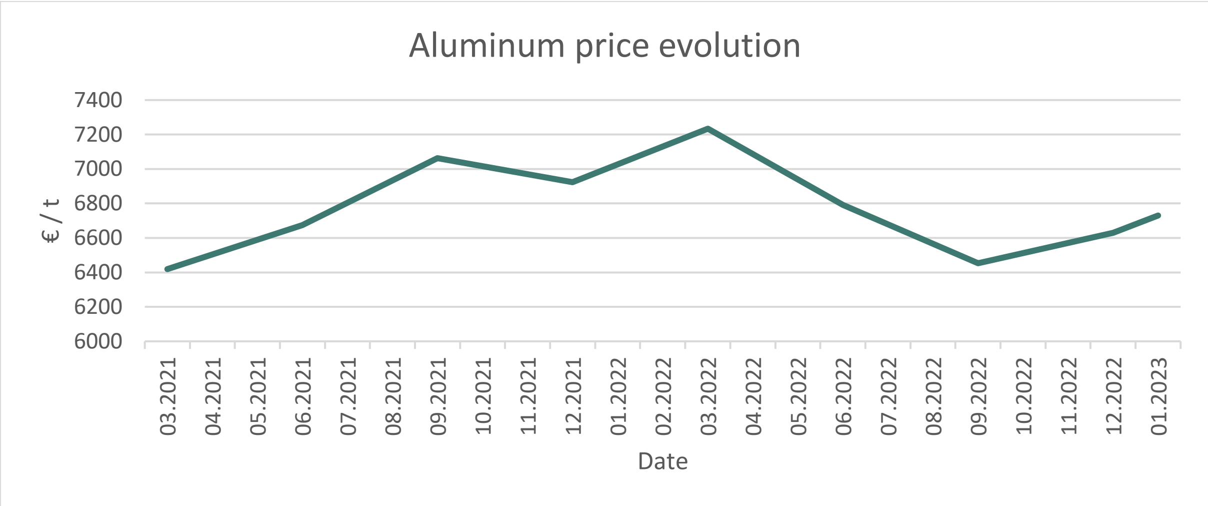

Figure 34: Aluminum price evolution (source: S.C. NAVROM Shipyard S.R.L. Galati / Gilinox)

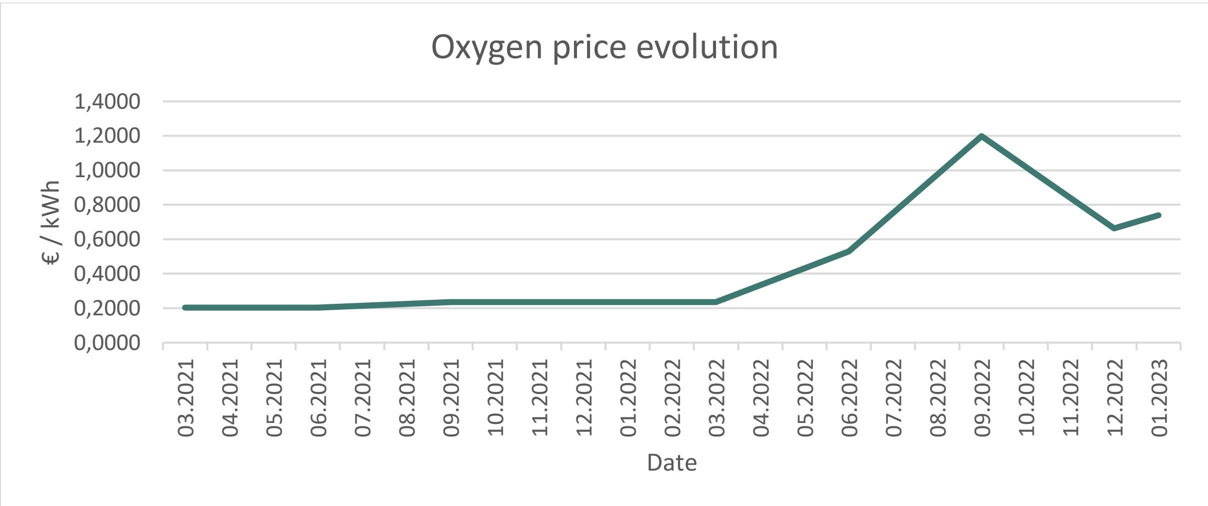

Figure 35: Oxygen price evolution chart (source: S.C. NAVROM Shipyard S.R.L. Galati / Linde Gas Romania)

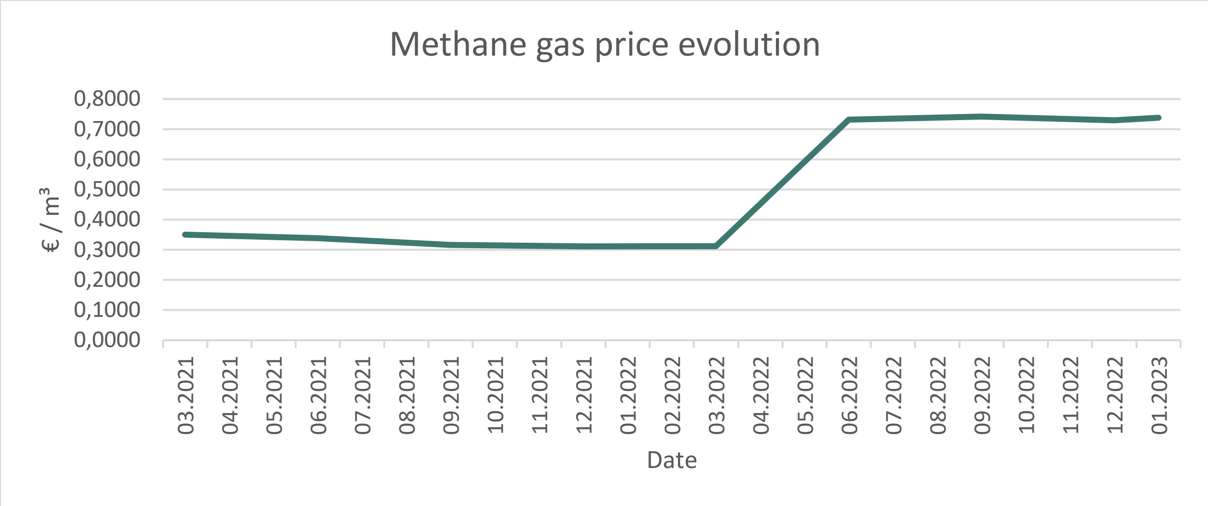

Figure 36: Methane gas price evolution chart (source: S.C. NAVROM Shipyard S.R.L. Galati / OMV Petrom)

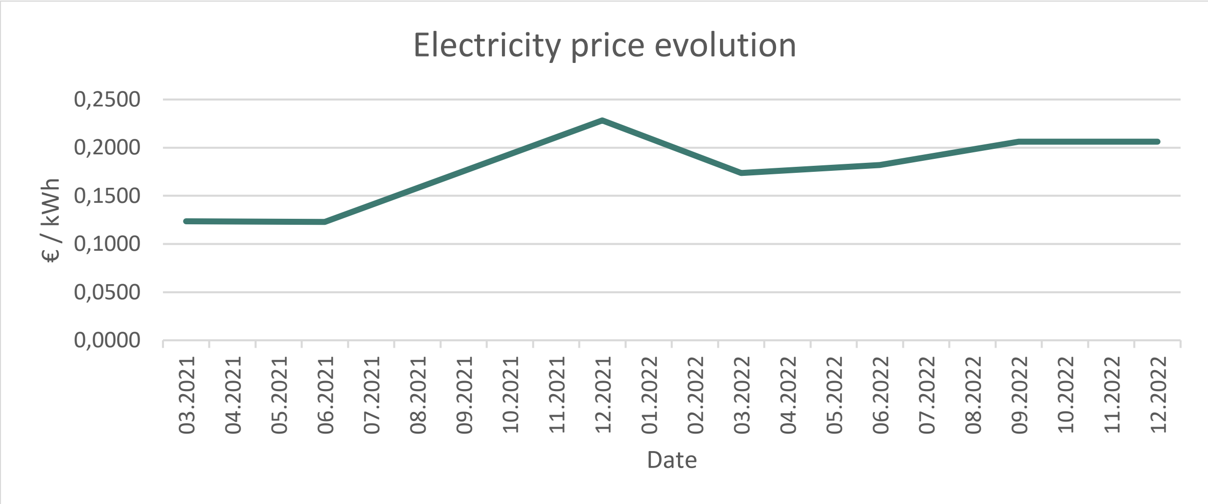

Figure 37: Electricity price evolution chart (source: S.C. NAVROM Shipyard S.R.L. Galati / Eletrica Furnizare SA)

4.4 Synthesis

In general, it can be stated that most of the new barge designs have a better or at least equivalent absolute container carrying capacity than the two benchmark designs Europa 2b and Europa 3a.

In case low water resilience is seen as the most important property the 005 IW-NET Containers transverse version can be regarded as the most favourable design, however, as pointed out above, this design has several operational disadvantages which would have to be weighed against.

As other aspects, in particular questions of stability and traffic safety (unobstructed view from the wheelhouse/sightlines), need to be considered, the best suited design can only be selected on an individual basis, taking into consideration the intended transport relations, the port equipment and the available pusher vessels.

5 Further considerations

In this chapter we analysed the new barge designs in detail regarding their optimisation for low water conditions.

5.1 Optimising barge designs for low water conditions

Optimising barge designs for low water conditions in essence means the reduction of the operational draught of a vessel in order to cope with low fairway depth.

In principle, there are three possible lines of approach to reach this goal:

- changing the shape of the vessel to achieve increased buoyancy.
- reducing the weight of the cargo
- reducing the weight of the barge itself

5.1.1 Changing the shape of the vessel to achieve increased buoyancy

As already pointed out above, a shoe-box-like shape would represent the best usage of Archimedes' principle. The major disadvantage of such a design would be a significantly increased hydrodynamic resistance, resulting in a dramatically deteriorated energy efficiency. From a naval architecture perspective this approach cannot be recommended for further investigation.

5.1.2 Reducing the weight of the cargo

With regard to the weight of the cargo a reduction of the amount of cargo carried will in general lead to a nearly linear reduction of the draught of the vessel. However, the reduction of the cargo carried, while being the easiest way to reduce the draught of the vessel, has the undesirable side-effect of automatically leading to diminished economic feasibility. This adaptation of the degree of loading is common practice, a further investigation seems to be redundant.

As the IW-NET project is placing a focus on container transport there is a further aspect that needs to be considered:

Most kinds of bulk or liquid cargo usually transported by inland waterway have a rather high specific weight, for example:

- iron ore 4,0 t/m³
- coal 1,6 t/m³
- gravel 1,8 - 2,7 t/m³
- diesel 0,82 - 0,86 t/m³
- petrol 0,72 - 0,78 t/m³

Sources: https://www.engineeringtoolbox.com/minerals-specific-gravity-d_1644.html, https://www.engineeringtoolbox.com/fuels-densities-specific-volumes-d_166.html

A 45' high cube container has a maximum gross weight of 34 t and a volume of 97,43 m³ (L 13,716 m * B 2,55 m * H 2,9 m). This translates to an average maximum specific weight of just 0,35 t/m³, which is considerably less than for usual bulk and liquid cargoes.

Therefore, from a practical point of view for the special case of container transport, the draught of the vessel can be seen as less critical than for other cargoes and containers can be regarded as a cargo that is better suited to low water conditions than most other cargoes.

5.1.3 Reducing the weight of the barge itself

The remaining line of approach is therefore the reduction of the weight of the barge itself. In general, the expectations concerning the practical effects of such reduction should not be set too high as the proportion of the weight of an average dry cargo barge in relation to its cargo carrying capacity can be estimated around 1:5 to 1:6 (e.g. lightship weight of barge 300 t, cargo carrying capacity 1500 – 1800 t). This means that a reduction of the lightship weight of the barge by, for example, 10 % translates to a reduction of the maximum loaded displacement of the barge by only around 1,4 to 1,8 % and a proportional reduction of the operational draught.

Furthermore, for keeping the cargo carrying capacity at approximately the same level it is necessary to also maintain the longitudinal strength of an alternative construction at approximately the same level as for the benchmark variant.

As already mentioned further above, three variations of construction material have been calculated for all barge designs:

- grade A shipbuilding steel (standard)
- aluminum with identical dimensions as the steel version (for demonstration purposes only – technically not correct!)
- aluminum with approximately the same longitudinal strength as the steel version

For the 004 IW-NET NEWS Evolution barge design additional variations have been taken into consideration:

- reduction of the side height of the barge
- use of high tensile steel for the girders
    - S355
    - S460

5.1.3.1 *Reduction of the side height of a barge*

The starting point for considerations regarding a reduction of the side height was, that with a high probability climate change will lead to prolonged periods of low water levels in the European inland waterway network so that vessels for considerable periods throughout a year will anyway not be able to use the full design draught. This notion is already clearly supported by evidence of actual water levels, in particular during the summer seasons of the last years.

The hypothesis is that a reduction of the side height of barges could lead to a lower lightship weight and thus to reduced draught and increased cargo capacity at shallow draughts. This hypothesis has been tested in a concrete calculation of lightship weight and longitudinal strength of the 004 IW-NET NEWS Evolution barge design.

For that purpose, a horizontal slice with a height of 500 mm has been cut out of the cross section:

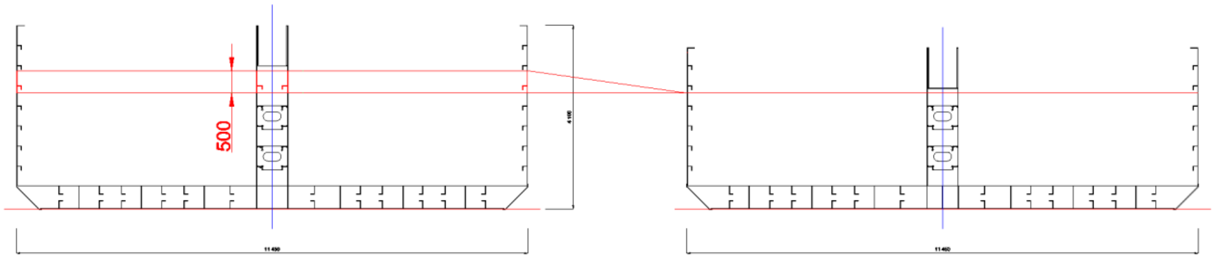

Figure 38: Cross section of a barge

When keeping all dimensions (plate thicknesses and girders) identical to the original design, the reduction of the side height results in a lightship weight of 388,276 t compared to 401,565 t of the original design (3,5 % lower). This would translate to a mean draught of 0,45 m, which is just 0,02 m (2 cm) less than for the original version. However, on the other hand the longitudinal strength of the barge with reduced side height with the same material dimensions is decreased significantly – the maximum permissible bending moment amounts to 11.485 t*m compared to 13.619 t*m for the original version. Hence a reduction in lightship weight of just 3,5 % leads to a loss of longitudinal strength of more than 15 %.

Redimensioning of plates and girders with a view to keep the longitudinal strength at approximately the same level as for the original version would – contrary to the hypothesis stated above – lead to a considerable increase in lightship weight to 461,976 t which is 60 t or 15 % more than for the original version. The mean draught of the empty vessel would then be 0,53 m, hence 0,06 m (6 cm) more than for the original version.

Annex 101 – Weight estimation 004 IW-NET NEWS Evolution – reduced side height
Annex 102 – Moment of inertia/section modulus 004 NEWS Evolution – reduced side height
Annex 103 – Section plan 004c3 IW-NET NEWS Evolution – reduced side height – same plate thickness
Annex 104 – Section plan 004c4 IW-NET NEWS Evolution – reduced side height – same longitudinal strength

5.1.3.2 *Use of high tensile steel for girders*

Grade A shipbuilding steel has a standard yield strength of 235 N/mm². High tensile steel, depending on the concrete type of steel, has considerably higher yield strength, which means that the same longitudinal strength can be achieved with profiles of smaller cross sections. The reduction of dimensions correlates proportionally to the reduction in weight that can be achieved as all steel types have more or less the same specific weight.

For practical reasons only the replacement of stiffeners and girders (standard profiles) has been considered. For the plate material grade A shipbuilding steel remains the material of choice, as a reduction of the plate thickness below the limit values set out in Article 3.02 of the ES-TRIN – which would be possible with high tensile steel – would require certification by a recognized classification society (which is not within the scope of this project).

For the following two types of high tensile steel lightship weight and longitudinal strength of the 004 IW-NET NEWS Evolution barge design have been calculated:

- S355 with a yield strength of 355 N/mm² (50 % higher than grade A shipbuilding steel)

- S460 with a yield strength of 460 N/mm² (95 % higher than grade A shipbuilding steel)

S355 standard profiles are available at usual marketplaces, S460 profiles are only available on specific order.

It shall be noted that high tensile steel is already used for some time in the automotive industry with the intention to save weight while at the same time maintaining high standards concerning crash resistance.

In order to take into account, the different material properties for plates and girders for the calculations of the moments of inertia the total cross section has been split into two partial cross sections, one consisting of the plate material, the other consisting of stiffeners and girders. The moments of inertia have been calculated separately for the two different cross sections and then been added.

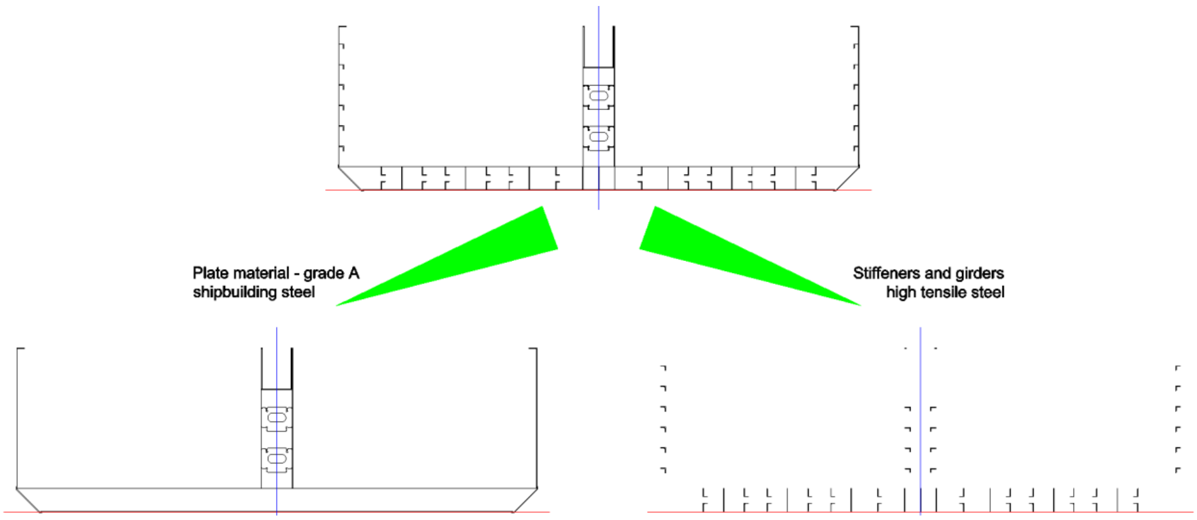

Figure 39: Cross sections of a barge (Plate material shipbuilding steel + stiffeners and girders out of high tensile steel)

This simplification is not entirely accurate as the centers of gravity of the sectional areas of the plate material on the one hand and the stiffeners and girders on the other hand do not exactly coincide and therefore there is a slight deviation between the neutral axes of the partial profiles. However, the resulting slight inaccuracy has been considered to be negligible for a first approximation.

	Original version – grade A shipbuilding steel	Plating in grade A shipbuilding steel - girders in high tensile steel S355	Plating in grade A shipbuilding steel - girders in high tensile steel S460
Lightship weight [t]	401,565	361,453	352,858
% of original version	100	90	88
Mean draught [m]	0,47	0,42	0,41

Figure 40: Comparison of construction materials

The reduction in weight would be approximately equivalent to the weight of 2 40 ft ISO-containers for the S355 version or 2 45 ft high-cube pallet-wide containers for the S460 version.

Regarding the building costs a comparison of different profiles available at major steel trading companies for S235 and S355 shows on average ca. 15 % of increase of the unit price. Profiles in S460 are apparently not normally available as far as the information on the respective websites goes but would have to be produced specifically on demand, which would imply a considerably higher price level.
For S355 profiles the reduction in steel weight, however, leads to the following rough estimation of building costs:

	Original version – grade A shipbuilding steel	Plating in grade A shipbuilding steel - girders in high tensile steel S355
Cross section plate material [cm²]	3631,041	3631,041
Cross section girders [cm²]	1006,416	509,096
Total cross section [cm²]	4637,457	4140,137
Percentage cross section	100	89
Percentage plating	78	88
Percentage girders	22	12
Cost factor plating	1,00	1,00
Cost factor girders	1,00	1,15
Cost estimation total	= (78*1,00 + 22*1,00)*(100/100)	= (88*1,00 + 12*1,15)*(89/100)
	100	91

Figure 41: Comparison original version (shipbuilding steel) and new version (shipbuilding steel with girders out of high tensile steel)

The surprising result of this rough estimation is that the overall building price for a barge using high tensile steel could be even lower than for a traditionally built barge due to the considerably lower amount of material used in total. However, it has to be noted that the table above only shows the cost for the building material – taking into account that labour and energy costs as well as costs for coating (corrosion protection) would constitute roughly two thirds of the total building costs a reduction of the material costs by 10 % as above would therefore translate to a reduction of total building costs by ca. 3 %.

Annex 105 – Weight estimation 004 IW-NET NEWS Evolution – high tensile steel
Annex 106 – Moment of inertia/section modulus 004 IW-NET NEWS Evolution – high tensile steel
Annex 107 – Section plan 004c5 IW-NET NEWS Evolution – high tensile steel S355
Annex 108 – Section plan 004c6 IW-NET NEWS Evolution – high tensile steel S460

5.2 Results

The results of the calculations described above show that the use of lightweight materials like aluminum can in principle provide considerably reduced lightship weight of the barge itself (on average about 70 % of the steel version) translating on average to about 12 cm less draught in all loading conditions, albeit with a relatively heavy price tag.

A reduction of the side height does not seem to be a viable course to follow as this would either result in dramatically lower longitudinal strength or in even higher weight of the original barge version if the longitudinal strength shall be kept at an equivalent level. Furthermore, a reduction of the side height would result in lower carrying capacity with a view to the statutory requirements on freeboard and safety distance, meaning that outside the low water periods the possible payload would be significantly reduced permanently.

As the most interesting option – rather unexpectedly – emerged the use of high tensile steel for girders and stiffeners. As for the other options under the presumption that approximately the same longitudinal strength should be maintained the total lightship weight could be reduced by about 10 % which would lead to a reduction of the mean draught of about 5 cm. At the same time, the building costs would be nearly the same like for grade A shipbuilding steel or even slightly less, owing to the lower total steel weight of the girder and stiffener material despite the higher unit cost for high tensile steel.

5.3 Synthesis

With a particular view to improved low water resilience, the use of high tensile steel for girders and stiffeners seems to be a very interesting option. However, as already mentioned above, container load in general is less sensitive to low water conditions due to the relatively low average weight in comparison to other types of cargo.

6 Comparing CO2 emission savings by using IWT instead of road

The European Green Deal (COM(2019) 640 final) sets out the aim to achieve a carbon neutral EU by 2050. This requires the decarbonization of all sectors. The transport sector is needed to achieve a 90% reduction in greenhouse gas emission by 2050 compared to 1990 levels. The transport sector is responsible for nearly a quarter of Europe's greenhouse gas emissions and has proven to be difficult to decarbonize. To support the greening of cargo operations, the European Green Deal calls for a substantial part of the inland freight traffic to shift away from road towards cleaner modes such as rail, inland waterways and short-sea shipping. The report by STC-NESTRA contributing to the GLEC (Global Logistics Emission Council) Framework concluded, that per ton-kilometre a saving of 70 % on GHG emissions can be reached, when shifting cargo from road to inland waterways along the Rhine corridor using containers. Individual companies and industry sectors will have to implement decarbonization strategies over the next few years. To identify how they can improve the performance of the logistics operations, they have to understand their current carbon footprint. The logical place to start is with detailed measurement of GHG emissions. For many companies, tracking GHG emissions from supply chain transportation is a challenge – little information is directly available from carriers. The quality of calculated emissions and emission intensities as well as their subsequent use in business reporting and decision-making concerning logistics emission reduction depends on availability, specification, quality and exchange of data. While for the road transportation sector the collection of data to demonstrate environmental performance improvements has progressed in the past, the availability of data on inland waterway transportation is scarce. Thus, to ensure an accurate comparison with other modes of transport, the measurement of energy consumption and related emissions of IWT needs to be qualitatively and quantitatively improved and brought up to the level of road traffic. In the domain of cargo transportation, the CO2 intensity of a given transport mode is commonly represented by observing CO2 emissions in relation to its transport performance and thus in the form of g/tkm or g/TEUkm. This ratio is generally referred to as the "CO2 emission factor". As is the case for other modes of transport, the CO2 intensity is the key element for determining the carbon footprint of inland navigation.

6.1 Latest developments in CO2 emissions calculations in the IWT sector

In this chapter we present the standards and tools for logistics emission calculation. Moreover, we investigate the status of emission values for IWT of each standard and tool. Starting with an explanation of the EN16258 and the GLEC framework which will lead into the ISO 14083 in 2023, we continue with an explanation of the tools Marco Polo, EcoTransIT World and Carbon Care. At the end of this chapter, we discuss results from studies focusing on the status of CO2 emissions of IWT in the standards and tools. CO2e (equivalent) is a unit of measurement designed to compare and aggregate the impact on global warming of all greenhouse gases (GHG) such as nitrous oxide (N2O), methane (CH4), perfluorocarbons, etc. It measures the 100-year global warming potential of GHG. It calculates the heat absorbed by any greenhouse gas for 100 years in the atmosphere as a multiple of the heat that would be absorbed by the same mass of CO2.

The calculations can be done with primary data, with program data, with detailed modeling or with default data. The used data has a direct influence on the accuracy of the results. It is important to gather high quality, consistent data and to specify the type of data and calculation approach used. Using primary data is the best option to get really reliable factors, but the access to primary data is often limited or unavailable. If no other data are available, the last resort is to use default data representative of average industry operating practices. The European standard EN 16258 represents a methodology for the calculation and declaration of energy consumption and GHG emissions of transport services for freight and passengers, which was published in 2012. The EN 16258 standard suggests the use of default values, if there is missing information about fuel consumption for vehicles, the load utilization and the proportion of empty trips. It has to be noted that if the energy consumption values are calculated using the default values rather than measured, then certain assumptions, e.g., about the load utilization of the vehicles, are considered in the calculation. These assumptions lead to considerable effects on the CO2e result. Sensitivity analyses – in which the assumed values are changed systematically – are recommended to reveal which input values have a crucial effect on the result. If it becomes clear that the default values have a marked effect on the result, they should be replaced by measured values. The Smart Freight Centre and a group of companies, associations and programs formed the Global Logistics Emissions Council (GLEC) and together developed the first GLEC Framework in 2016. The GLEC Framework was updated 2019 into the GLEC Framework 2.0. The GLEC framework in its third version serves as the basis for the new ISO 14083 which will replace the EN16258 by the end of 2022. It can be implemented by shippers, carriers and logistics service providers. It provides not only one prescriptive approach to the calculation, but base methodologies that can be used. Concerning inland waterway freight transport, the existing GLEC framework provides global default consumption factors without further (regional) distinction between e.g., vessel types, sizes, (operational) power and load factors. The data are primarily based on European operational information on the Rheine and combined according to weighted averages for common vessel categories. It is well known that the nature of the waterway system can have a significant impact both on the type and size of vessel that can navigate it and the ease of transit due to the prevalence of locks, underwater clearance and speed of flow. Therefore, in-country data should be sought wherever possible. Aggregated trade lane emission intensity factors for barges based on major waterways and their operational characteristics would be the ideal scenario for the future. Moreover, factors for alternative fuels others than diesel cannot be found. Therefore, SFC has the objective to integrate a more detailed methodology for inland waterways into the third update of the GLEC framework which is planned by the end of 2022.

In 2012, the Central Commission for the Navigation of the Rhine (CCNR), the international institution with an administration which is responsible to address effectively several subjects concerning inland navigation on the Rhine, noted that many studies have attempted to quantify the CO2 intensity of inland navigation. The CCNR found that the reviewed studies found a broad range of CO2 intensity values for inland navigation. In fact, the range of the CO2 values was too broad to determine reliable carbon footprint of inland navigation for the purposes of transport, climate protection policy or to accurately derive the CO2 emissions of logistics chains. Besides other studies, the CCNR investigated the emission data used by the Marco Polo Calculator and EcoTransIT World, which are described in the following paragraphs. In the Marco Polo calculator, the user can compare the monetized environmental impacts of the former road route with the shifted route to railway or inland waterways. The tool is a Microsoft Excel-based application and can be downloaded for free from the internet but provides only monetized outputs. EcoTransIT World (Ecological Transport Information Tool, worldwide) is a free and publicly available web application, which calculates the environmental impact of freight transport for any route and transport modality. EcoTransIT offers a chargeable Business Solutions, which supplies the user with significantly extended options. The emission data from the Marco Polo Calculator and EcoTransIT and real-life data provided by the shipping industry differ greatly, CCNR (2012) concluded, that the Marco Polo Calculator and EcoTransIT are based on data for the specific energy consumption of inland navigation that has neither been verified in practice nor compared with a study based on real data. The CCNR suggested that the emission factors available or to be redeveloped should be checked using the data from inland navigation companies on fuel consumption and the total transport performance of various vessel types in conjunction with the transport statistics recorded by the CCNR (2012). Another global emission calculator based on the EN16258 standard is Carbon Care which covers all modes of transport (road, rail, air, sea and inland waterways), emissions from cargo handling and cold storage. In addition to a free-of-charge version resulting in simple online CO2 calculations, Carbon Care offers advanced automated computation of the GHG generated by the transportation of goods.

Schweighofer and Szalma did an evaluation of a one-year operational profile of a Danube vessel and found significant variations in the relative fuel consumption depending on the locations and times considered. They calculate the respective CO2 emissions by multiplying the fuel consumption with a factor and concluded, that an unambiguous calculation of the CO2 emissions was not possible, using the EcoTransIT emission calculation tool. The definition of the input parameters in the tool was too confusing in order to establish confidence in the results obtained (e.g. a vessel load factor of 100 % results in less total CO2 emissions in t as the ones obtained with a vessel load factor of 50 %). They concluded that the results of the EcoTransIT emission calculation tool must be taken with caution if transports with inland waterway vessels are considered on the Danube.

Simenc evaluated existing emission calculator that could be used for estimating emissions of IWT and concluded that the range of available ready-to-use practical solutions is relatively narrow. There are few options available and even the estimation capabilities of existing ones could be thought of only as educated guesses, at best. They are only as good as the quality of emission factors and other parameters that are considered, over which the prospective users have no influence and are subject to uncertainties regarding the underlying calculation algorithms and ability to produce reliable results.

Van Liere focused on refining modal default carbon footprint factors for GLEC Framework 2.0. to further increase the accuracy of logistics emissions in global supply chains. Therefore, they calculated the GHG emission factors for representative vessel classes in Europe based on real-life data from barge operators for multiple trips or year-round navigation. Primary sources were the European research project PROMINENT and few companies that provide IWT services. Nevertheless, they note, that the GHG emission factors considered are still estimates rather than exact values. For example, in practice substantial differences can be experienced on similar trips carried out by similar vessels. This can be caused by differentiated water levels and currents, different load factors, operational profile and related power distribution. The dataset includes information on only approx. 1% of the vessels operating in Europe. They recommended to continue expanding the dataset with annual information on transport performance (distance covered, load factor, tones transported) and fuel consumption per representative vessel class and emphasize the value of real-life data, because the data collected by barge owners / inland shipping lines has resulted in lower GHG emission factors in comparison to other recognized studies. To reach global representative GHG emission factors for IWT more effort is needed. Validation of European GHG emission factors could be a first step, to be followed by onboard measurements on the most important river basins / waterways in the World. In conclusion, the review of related literature shows that there are already many efforts in the direction of standardisation in carbon accounting and in the area of default values. However, the lack of harmonization and generability of calculation results may still represent a barrier to overcome.

6.2 Transport example: Comparing CO2e emissions savings by using IWT instead of road transportation

For the transport analysis we used the following transport case: 21 containers with each 21 tons of average goods (weight type) are transported via truck (diesel propulsion) from St. Florian (Austria: coordinates: 48.20505 / 14.37790) to Enns (Austria: coordinates: 48.2254 / 14.4933). In Enns, the goods are transferred to an inland vessel and transported along the Danube to Constanta (Romania). The navigable length of the Danube available to international waterway freight transport is 2,415 kilometers, starting from Sulina at the end of the middle Danube distributary into the Black Sea in Romania (river-km 0) to the end of the Danube as a German federal waterway at Kelheim (river-km 2,414.72). From Regensburg to Budapest (except for the Straubing–Vilshofen section in Bavaria) the Danube is classified as waterway class VIb and is navigable by 4-unit pushed convoys (viadonau, 2019). A motor cargo ship (length: 85 m, width: 9.5 m, max. draught 2.5 m, max. load capacity 1,350 t) with diesel propulsion takes the goods further to Constanta (Romania: coordinates: 44.0989 / 28.6572) and then again via truck (diesel propulsion) to Ovidiu (Romania: coordinates: 44.25762 / 28.55861). According to Transport Trade Services GmbH, the waterway distance is 1,872 km (Leitner, 2022). We compare this example with trucks going directly from St. Florian (Austria: coordinates: 48.20505 / 14.37790) to Ovidiu (Romania: coordinates: 44.25762 / 28.55861).

Calculation with default values from GLEC Framework

In the first step we calculate the CO2e emissions from the road transportation and the inland waterway transportation with the GLEC Framework. We start with the road transportation.

<u>*Road*</u>

The distance from St. Florian (AT) to Ovidiu (RO) according to google maps is 1,747 km. And we need 21 diesel trucks to transport 21 containers a 21 t.

St. Florian (AT) to Ovidiu (RO)	
Main run	Truck
Distance	1747 km
Tonnage	441 t (21 Container a 21 t)

Figure 42: Road transport from St. Florian to Ovidiu

We calculate 1,747 km x 441 t= 770,427 x 75 / 1,000,000 = **57.78 t CO2e**

The number of 75 is the WTW default value from the GLEC Framework for an artic diesel truck up to 40 t for containers (see: Table 19). 57.78 t CO2e is emitted to transport 414 tons from St. Florian to Ovidiu by truck.

Table 42. Europe and South America road emission intensity factors

Vehicle characteristics and size	Load characteristics	Basis		Fuel	Consumption factor (kg/t-km)	Consumption factor (l/t-km)	Emission intensity (g CO_2e/t-km)		
		Load Factor	Empty Running				WTT	TTW	WTW
Rigid truck 3.5–7.5 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.098	0.118	74	300	370
				CNG	0.117	-	45	310	360
Rigid truck 7.5–12 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.062	0.074	47	190	240
				CNG	0.073	-	28	190	220
Rigid truck 12–20 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.040	0.048	30	120	150
				CNG	0.050	-	15	130	150
				LNG	0.050	-	46	130	180
Rigid truck 20–26 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.033	0.039	26	99	130
				CNG	0.038	-	15	100	120
				LNG	0.038	-	36	100	140
Rigid truck 26–32 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.026	0.031	20	78	98
	Container	72%	30%		0.023	0.027	18	69	87
Artic truck up to 34 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.024	0.029	18	74	92
	Container	72%	30%		0.027	0.033	21	83	100
Artic truck up to 40 t GVW	Average/ mixed	60%	17%	Diesel, 5% biodiesel blend	0.021	0.025	16	64	80
	Container	72%	30%		0.020	0.024	15	60	75
	Average/ mixed	60%	17%	CNG	0.024	-	10	66	75

Table 19: Road transportation default values in the GLEC framework

Inland vessel:
According to google maps the transport distance between St. Florian (AT) and the port of Enns (AT) is 11.1 km. The distance for the main run from the port of Enns (AT) to the port of Constanza (RO) is 1,872 km and the distance from Constanza (RO) to Ovidiu (RO) is 26,7 km (google maps; see Table 20).

St. Florian (AT) to Ovidiu (RO)	
Pre-carriage	Truck
Distance	11.1 km
Main run	Inland vessel
Distance	1,872 km
Post-carriage	Truck
Distance	26.7 km
Tonnage	441 t (21 Container a 21 t)

Table 20: Transport with an inland waterway vessel from St. Florian to Ovidiu

We first calculate the pre-carriage and use default values from the GLEC for the diesel artic truck up to 40 t.

11.1 km x 441 t= 4,895.1 x 75 / 1000000 = 0.367 t CO2e
Then we calculate the main run and use the default value of a motor vessel 85-110m (1,000-2,000 t) of 19 g CO2e/t-km from the GLEC Framework (see Table 21).
1,872 km x 441 t = 825,552 x 19 / 1,000,000 = 15.685 t CO2e
Then we calculate the post carriage with the default values from the GLEC for the diesel artic truck up to 40 t.
26.7 km x 441 t = 11,774.7 x 75 /1,000,000 = 0.883 t CO2e
16.935 t CO2e (0,367 + 15,685 + 0,883) is emitted to transport 414 tons from St. Florian to Ovidiu by a multimodal transport.

Table 36. Inland waterways transport emissions intensity factors

Vehicle characteristics and size	Loading Basis Combined Load Factor & Empty Running	Fuel	Consumption factor (kg/t-km)	Consumption factor (l/t-km)	Emission intensity (g CO_2e/t-km) WTT	TTW	WTW
Motor vessels <- 80 m (<- 1000 t)	55%	Diesel	0.0076	0.0091	5.2	24	30
Motor vessels 85–110 m (1000–2000 t)	52%		0.0048	0.0058	3.3	15	19
Motor vessels 135 m (2000–3000 t)	50%		0.0049	0.0059	3.4	16	19
Coupled convoys (163–185 m)	61%		0.0044	0.0052	3.0	14	17
Pushed convoy – push boat + 2 barges	70%		0.0044	0.0053	3.1	14	17
Pushed convoy – push boat + 4/5 barges	70%		0.0025	0.0030	1.7	8.0	10
Pushed convoy – push boat + 6 barges	70%		0.0019	0.0023	1.3	6.1	7.4
Tanker vessels	65%		0.0055	0.0066	3.8	18	21
Container vessels 110 m	75%		0.0065	0.0079	4.5	21	26
Container vessels 135 m	75%		0.0051	0.0061	3.5	16	20
Container vessels – Coupled convoys	68%		0.0051	0.0061	3.5	16	20

Pushed convoy data applicable to US operations.

Table 21: Inland waterway default values in the GLEC Framework[1]

To conclude to transport 441 t from St. Florian to Ovidiu, 57.78 t of CO2e are emitted going by truck and 16.935 t of CO2e are emitted by a multimodal transport with inland waterway and trucks. The potential to save CO2 is therefore quite substantial, although the emissions from the transshipment in the multimodal transport is not included. For emissions which are related to handling, the data situation is currently inadequate and further research is needed.

Calculation with detailed modelling data and EcotransIT

To show the differences in the results when calculation emission with different data sources we now want to compare the results from the calculation with the default values with the results obtaining when calculation with modelling data. Therefore, we use the free available version of EcoTransIT and the same transport example from St. Florian (AT) to Ovidiu (RO) first by truck and then as multimodal transport.

1 https://www.smartfreightcentre.org/en/

Road:

According to EcoTransIT the distance between St. Florian and Ovidiu is 1,459.08 km (see Table 22) using the coordinates as in google maps, where we got a distance of 1,747 km. The truck is a diesel truck (26-40 t), Euro 5. The result is 46 t CO2e (see Figure 42).

Table 22: Distance from St. Florian to Ovidiu calculated with EcoTransIT

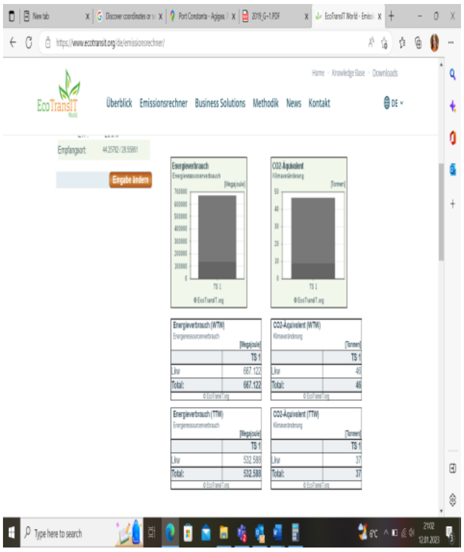

Figure 43: Result from EcoTransIT for the road transportation from St. Florian to Ovidiu

Inland vessel:

For calculating the emission for the multimodal transport in EcoTransIT we use the following input parameters (see Figure 43). For the pre- and the post carriage we use an diesel truck (26-40 t), Euro 5 and the inland vessel is an Euro ship bulk I-IV (0-1,500 t capacity). The calculated distances are 10.58 km from St. Florian to the port of Enns, 1,789,65 km from the port of Enns to the port of Constanta and 17.25 km from Constanta to Ovidiu.

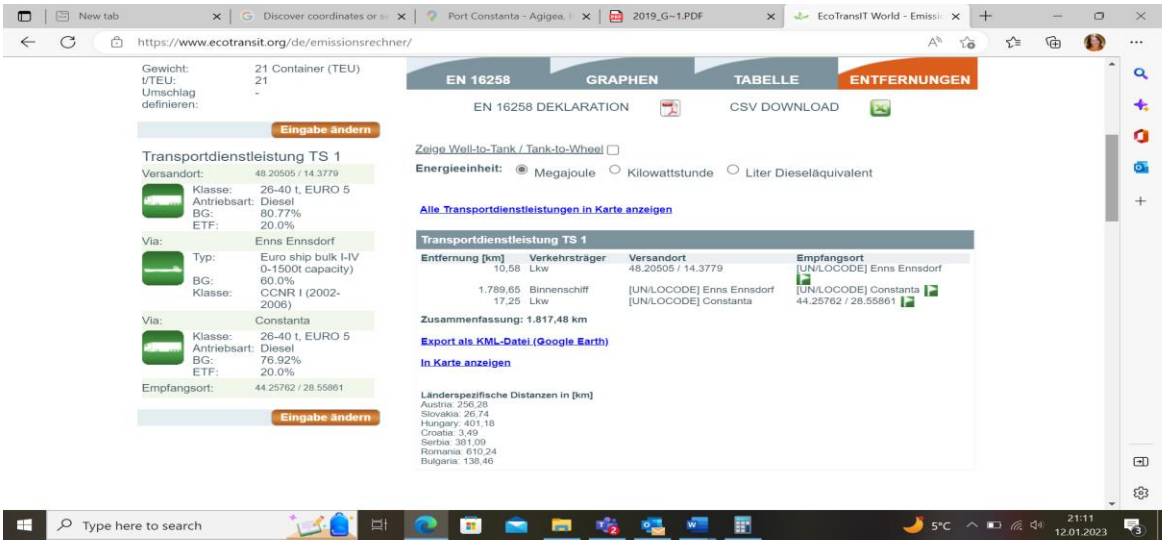

Figure 44: Input parameters and distance for the multimodal transport between St. Florian and Ovidiu

The result is 24,11 t CO2e (see Figure 44).

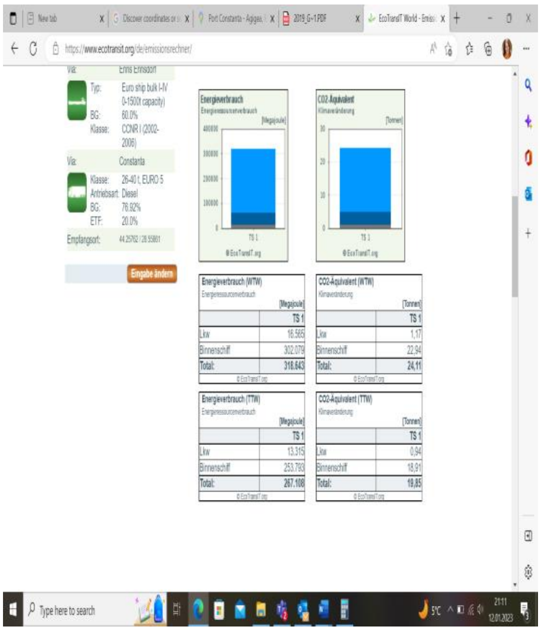

Figure 45: Result from EcoTransIT for the multimodal transport from St. Florian to Ovidiu

To conclude to transport 441 t from St. Florian to Ovidiu, 46 t of CO2e are emitted going by truck and 24.11 t of CO2e are emitted by a multimodal transport with inland waterway and trucks. The potential to save CO2 is here also quite substantial, although it is lower, as in the calculation with the default values. The CO2 emissions from the handling is also not included, respectively specified with 0.

6.3 Synthesis

We can see that there is a great potential to save CO_2 emissions in our transport example when using multimodal transport with an inland waterway vessel instead of a transport only by truck. Of course, this is just one example, and we see that the results are different depending on the input parameters and the data source. The calculation of many transport examples and the comparison with different methods and tool could provide important further insights into savings. Moreover, it should be a goal to get more primary data (fuel consumption) or actual emissions for calculating transport emissions. Within the truck industry this is easier, because of the limited engines and sensors to be applied. Measuring emission can be done cost-efficient. For inland shipping this is more challenging. It is not only the main engine(s), but also auxiliary equipment and engines, making it very costly to equip the whole vessel with sensors to calculate emissions of the whole vessel. The handling is not included in the calculations, although it is an important component in multimodal transport. Because the improved access to reliable data will help both business and governments make better decisions to collectively reach climate goals.

7 Conclusions

We defined the following boundaries for our new barge design options for fluctuating water conditions by carrying out an analysis of suitable cargo to be transported, an infrastructural analysis of bridges and locks on the Danube to identify the maximum possible dimensions of our new barge design options, and an analysis of ports, which have suitable equipment to handle and transship the chosen 45' pallet-wide high cube containers.

We agreed on containers, as cargo to be carried by our newly designed barge options. On the one hand to attract new customers on the Danube, as there are hardly any container transports on the Danube today and thus, promote multimodality. On the other hand, because containers have a low density in comparison to other goods and are therefore particularly suitable for low and fluctuating water conditions. More precisely, 45' pallet-wide high-cube containers were defined, which are widely used in road and rail transport across Europe. The new barge design options should be designed to serve on the Danube, between the port of Enns (Austria) and Giurgiu (Romania). Both selected ports have sufficient equipment to handle and transship 45' pallet-wide high-cube containers. Regarding the maximum measures of the barge designs, the analysis of locks and bridges revealed that a maximum length of 97,50 m and a maximum breadth of 11,45 m should be considered.

After defining the boundaries for the new barge designs, the designs were generated using Naval Architecture CAD. In total six barge design options were designed. After the evaluation of the barge design, it can be stated stat there is no single optimum solution. Barge design will always need to be optimized for a concrete application and to the specific requirements of its future operator, taking into account the available infrastructure for the intended area of navigation. Therefore, each design is useable and offers advantages and disadvantages depending on the specific used case. Nevertheless, considering the currently available barge types (001 Europa 2b and 002 Europa 3a) there is considerable room for improvement regarding to accommodating 45' high-cube pallet-wide containers. The logistics experts within the iw-net consortium identified a minimum number of 30 45' containers per barge as a threshold to achieve competitive freight rates in comparison to road and rail transport in the Danube corridor. This container capacity can be transported by the new barge design, often even exceeding it, while the currently available barge types are not able to carry this number of containers due to capacity constraints. In general, it can be stated that most of the new barge designs have a better or at least equivalent absolute container carrying capacity than the two benchmark designs Europa 2b and Europa 3a.

The in-depth analysis of the new barge designs focused on different aspects, such as low water resilience of the designs, stability and sightlines, as well as possible construction materials. Regarding low water resilience the "005 IW-NET Containers transverse" design can be named as the most favourable design, however, as pointed out above, this design has a number of operational disadvantages which would have to be weighed against. Considering stability and traffic safety issues (unobstructed view from the wheelhouse/sightlines) the best suited design can only be selected on an individual basis, taking into consideration the intended transport routes and the available pusher vessels. As the new barge designs should be suitable particularly with a view on low fluctuating water conditions the use of high tensile steel for girders and stiffeners seems to be a very interesting option. However, as already mentioned above, container load in general is less sensitive to low water conditions due to the relatively low average weight in comparison to other types of cargo. As a last step of our analysis, we took a transport example to show that there is a great potential to save CO2 emissions using multimodal transport by inland waterway vessel instead of a transport only by truck.

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