SUSTAINABLE WATERWAY TRANSPORT, CLEAN AIR

CLINSH Fleet scenarios

Deliverable D2.4

CLEAN INLAND SHIPPING

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Goal:	The objective of LIFE CLINSH is to improve air quality in urban areas situated close to ports and inland waterways, by accelerating IWT emission reductions.
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Glossary

Abbreviation	Meaning
CBA	Cost-Benefits Analysis
CCNR	Central Commission for the Navigation of the Rhine
CCNRI/CCNRII	Emission standards for inland waterway vessels
CEMT	Conférence Européenne des Ministres du Transport
CEMT I-VI	Waterway classes established by the CEMT, laying down maximum vessel dimensions for each class
CLINSH	Clean Inland Shipping project under LIFE+ program
CO_2-eq	Carbon dioxide equivalent
DPF	Diesel particulate filter, to reduce particulate emissions
dwt	Deadweight tonnage: the total mass a shipping vessel can carry (load, fuel, ballast water), expressed in tonnes
FWE	Fuel-water emulsion
GTL	Gas-to-liquids, a synthetic diesel oil made from natural gas
HVO	Hydrotreated Vegetable Oil
IWT	Inland waterway transport
kW	Kilowatt
kWh	Kilowatt-hour
kton	Kiloton
LNG	Liquefied Natural Gas
MJ	Megajoule
NO_x	Collective term for mono-nitrogen oxides (NO, NO_2 and NO_3), emissions which lead to smog formation, environmental acidification and respiratory damage
PV	Passenger vessel
PB	Push boat
PM	Particulate matter
$PM_{2.5}$	Particulate matter smaller than 2.5 micrometre
PM_{10}	Particulate matter smaller than 10 micrometre
ppm	Parts per million
SCR	Selective Catalytic Reduction, an exhaust gas treatment system to reduce NO_x emissions
Stage IIIa, IV, V	European emission standards for non-road mobile machinery (NRMM), such as construction equipment, railroad engines, inland waterway vessels, and off-road recreational vehicles (Regulations: 2004/26/EC, (EU) 2016/1628).
TEU	Standard shipping container size expressing container volume: Twenty feet Equivalent Unit
tkm	Tonne-kilometre: unit of transport performance expressing transport of one tonne over one kilometre
TTW	Tank-to-wake emissions: emissions arising from fuel combustion during vehicle use
vkm	Vehicle-kilometre
ZE	Zero-emission

Contents

1 Introduction

1.1 Context

The main objective of CLINSH is to improve air quality in urban areas by accelerating emission reductions in Inland Waterway Transport. Important sub-goals within the CLINSH project are:
- to demonstrate the effectiveness of greening measures in the IWT sector;
- to stimulate the sector to personally take these greening measures;
- to contribute to improving air quality.

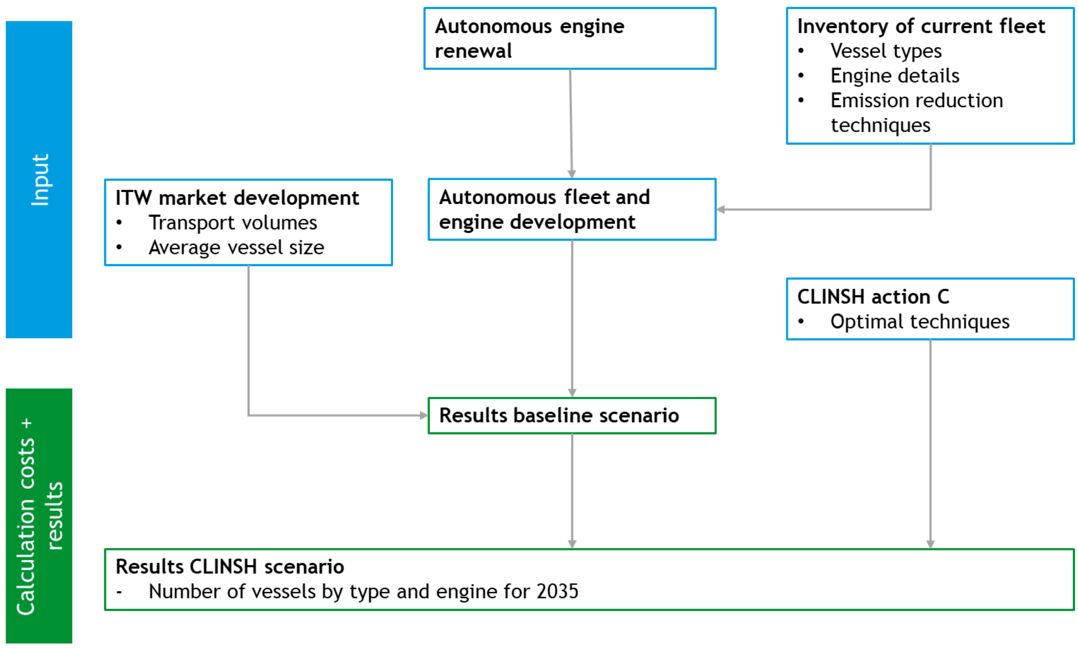
In Action D, related to the last two sub-goals, the CLINSH consortium develops and advises on policy instruments to stimulate the greening of the sector and to improve air quality. This deliverable reports on Task D2.4 where we have developed fleet scenarios which are used to assess the effect of the CLINSH policies (Action D2.1) on the fleet performance. The fleet scenarios are used in Task B2.3 to calculate the effect on the emissions of the fleet and in Task B2.4 to show the effect on air quality. The fleet scenarios together with cost and benefit analysis in Task C1 are also used to calculate the financing requirements for the CLINSH scenario in Task D2.3.

1.2 Goal

The goal of the fleet scenarios in Action D2.4 is to assess the effects of air quality when promoting CLINSH policies for the development of the inland waterway fleet towards 2035. In order to do this, we have constructed two scenarios: a baseline scenario describing the development of the fleet without any policy measures, and the so-called CLINSH scenario where emission reduction measures are taken according to a social costs optimum perspective (based on the results of Action C1). These fleet scenarios are used in other actions/tasks to quantify the effect on emission and air quality.

Figure 1 shows the methodology used to construct the fleet scenarios. The baseline scenario is constructed based on the expected renewal of the current fleet and market forces that influence the inland waterway market. The CLINSH scenario builds on the baseline scenario and the social optimal emission reduction options (based on Action C1).

Figure 1 - Methodology for development of fleet scenario



1.3 Scope

The inland waterway fleet in scope is the North West European fleet based on the database developed by the study PROMINENT (Stichting Projecten Binnenvaart, 2016). For this study we have categorised the fleet in 28 vessel classes according to vessel size and operational profile.
This assessment focusses on the development towards the year 2035, which is the year when the impact of CLINSH measures on emission and air quality will be assessed. We expect that large scale uptake of zero-emission technologies will take place after 2035. As it is still unclear which zero-emission technologies will prevail we focus our analysis up to 2035. In Action B2.3 (emission scenarios) the fleet characteristics (engine type and fuel type per ship category) will be applied on the observed ships movements by AIS, to calculate the total emissions of the fleet.

1.4 Readers guide

In Chapter 2 we start with describing the development of the fleet in Northwestern Europe in the baseline scenario. In Chapter 3 we give a summary of the analysis performed in C1 on the social costs of different emission reducing technologies per ship class. The analysis gives insight on the emission reduction potential as well as the costs and benefits for the ship owner and society. The CLINSH scenario is based on stimulating the technologies with the lowest social costs. The results of the analysis are therefore an important input for the CLINSH scenario. Chapter 4 describes the fleet characteristic in the fleet scenario. Finally, Chapter 5 provides a summary of the results and discusses the main conclusions.

2 Baseline scenario

2.1 Introduction

In this chapter we describe the fleet development for the inland waterway fleet in Northwestern Europe in the baseline scenario. The focus is on the number and type of engines and fuels applied by the different ship categories. The baseline scenario assumes no new policies to increase adoption of emission reducing technologies. Only the effect of established policies (date December 2020), such as European Stage V regulation for new engines and the environmental zone in the Port of Rotterdam is taken into account. Paragraph 2.2 summarises the calculation steps taken to construct the baseline scenario. Paragraph 2.3 shows the results for the baseline scenario.

2.2 Calculation steps

The baseline scenario is constructed using five calculation steps. A detailed overview of the individual calculation steps is provided in Annex A. The steps are the following:

1. The first step is to identify the current fleet. This involves making an overview of the number of vessels, the type of vessels, and the number, type and year of build of engines used by the identified vessels. Emission reduction technologies in current vessels are also included.
   The inventory of the manufacturing years of engines enables modelling of an engine renewal schedule in the absence of policy measures.
2. The second step is to model the autonomous renewal of engines. This requires collecting information on the lifetimes of engines. In combination with the manufacturing years of engines identified in Step 1, the engine lifetime enables to predict the year of engine replacement.
   The result is a model that predicts the replacement of engines for all vessels currently in the Northwestern European fleet.
3. The third step is the introduction of market developments that influence the components of the inland waterway transport fleet. This step can be divided into two parts:
   a. First we have investigated the development of transport volumes. Increases or decreases in certain product types will change the demand for specific types of vessels.
   b. The second part is the inclusion of the development of average vessel size. It is expected that the observed trend of increasing average ship size will continue.
4. The fourth step is to combine the results from Step 2 and Step 3 and construct the development of the number of engines by vessel type. The outcome will be a distribution of engine types, by manufacturing year, used by various types of inland vessels.
5. The average number of engines by vessel types and the results of Step 4 are used to calculate the number of vessels by vessel type in the future years. The baseline scenario thus provides the development of the number of vessels, by vessel type, as well as the associated number of engines.

2.3 Results baseline scenario

The results for the fleet composition in 2020 are shown in Table 1. The majority of engines used in 2020 are unregulated, CCNR1 and CCNR2 engines. There are however large differences between vessel classes. Vessels with many sailing hours, for example push boats ≥ 2,000 kW and coupled convoys, have a higher share of newer CCNR2 engines. Vessels with less sailing hours, and therefore longer engine lifetimes, have on average older engines. There are also already certain vessels sailing on LNG and with SCR + DPF currently. In 2020 there were no (or hardly any) Stage V engines.

Towards 2035 we have identified developments that influence the constitution of the inland waterway fleet. There will be a large decrease of transport of coal as coal-fired power plants are shutting down. Also, the transport demand for petrol and diesel will start decreasing due to increased electrification of road transport. Transport demand for other commodities, for example containers and chemical products, is expected to increase. As a result we expect a small increase of total transport volumes in 2035 compared to 2020 (see details in Annex A).

Table 1 – Number of vessels per technology in the baseline scenario in 2020

Fuel	Diesel					LNG
Engine type Vessel type	Unregulated	CCNR1	CCNR2	Stage V	SCR + DPF	LNG monofuel
Passenger vessel < 250 kW	458	23	40	-	-	-
Passenger vessel 250-500 kW	191	10	26	-	-	-
Passenger vessel 500-1,000 kW	44	3	13	-	-	-
Passenger vessel > 1,000 kW	25	49	86	-	-	-
Push boats < 500 kW	118	6	32	-	-	-
Push boats 500-2,000 kW	14	30	41	-	3	-
Push boats ≥ 2,000 kW	0	0	12	-	-	-
Motor vessels < 80 m length	797	452	376	-	-	-
Motor vessels dry cargo typical 80 and 86 m ship	293	235	142	-	24	-
Motor vessels dry cargo typical 105 m ship	55	90	94	-	8	-
Motor vessels dry cargo 110 m ship	3	187	164	-	12	-
Motor vessels dry cargo > 130 (135 m ship)	3	85	122	-	7	-
Motor vessels liquid cargo 80-109 m length (typical 86 m ship)	61	98	197	-	13	-
Motor vessels liquid cargo 110 m ship	4	148	336	-	18	10
Motor vessels liquid cargo > 130 (135 m ship)	1	34	126	-	6	-
Coupled convoys	5	41	86	-	5	1
Ferry	335	76	195	-	-	6
Tugboat and workboat	413	3	64	-	-	-
Total	**2,819**	**1,571**	**2,155**	**-**	**96**	**18**
Grand total	**6,657**					

In recent decades the average vessels size has increased. The number of active inland waterway vessels has decreased while the total transport capacity of the fleet has remained stable. We expect that this trend will continue and as a result the number of smaller vessels decreases, while the number of larger vessels increases. These trends are combined with the autonomous renewal schedule of engines. Table 2 shows the results of the modelling.

The results show that in 2035 a considerable amount of vessels is still using unregulated or CCNR1/CCNR2 engines. For vessel categories with many sailing hours a relatively higher share of Stage V engines will be installed in 2035 as these vessels replace engines sooner. In the baseline scenario, due to the absence of policies, there will be no additional vessels applying technologies that increase end user costs, like SCR + DPF. The numbers of vessels applying SCR + DPF and LNG included in the baseline scenario are due to existing policies.

Table 2 - Number of vessels per technology for baseline scenario in 2035

Fuel	Diesel					LNG
Engine type Vessel type	Unregulated	CCNR1	CCNR2	Stage V	SCR + DPF	LNG monofuel
Passenger vessel < 250 kW	289	23	40	169	-	-
Passenger vessel 250-500 kW	140	10	26	51	-	-
Passenger vessel 500-1,000 kW	35	3	13	9	-	-
Passenger vessel > 1,000 kW	18	48	86	78	-	-
Push boats < 500 kW	47	6	62	43	-	-
Push boats 500-2,000 kW	-	11	26	47	3	-
Push boats ≥ 2,000 kW	-	-	-	13	-	-
Motor vessels < 80 m length	252	387	488	252	-	-
Motor vessels dry cargo typical 80 and 86 m ship	111	242	240	128	25	-
Motor vessels dry cargo typical 105 m ship	1	70	136	46	9	-
Motor vessels dry cargo 110 m ship	-	146	161	81	13	-
Motor vessels dry cargo > 130 (135 m ship)	-	27	81	124	8	-
Motor vessels liquid cargo 80-109 m length (typical 86 m ship)	20	98	226	40	13	-
Motor vessels liquid cargo 110 m ship	-	120	327	106	20	12
Motor vessels liquid cargo > 130 (135 m ship)	-	11	81	80	6	-
Coupled convoys	-	10	48	80	5	1
Ferry	282	77	197	59	-	6
Tugboat and workboat	240	3	64	173	-	-
Total	**1,429**	**1,263**	**2,302**	**1,579**	**103**	**19**
Grand total	**6,694**					

3 Summary social costs and benefits

3.1 Introduction

Action C in the CLINSH project investigated the social costs and benefits of several emission reduction technologies and fuels. This chapter summarises the main findings from Action C.

The main goal of the CLINSH project is to reduce air pollutant emissions from inland waterway transport. The problematic air polluting emissions from combustion in diesel engines are nitrogen oxides (NO_x) and particulates or soot (PM). To reduce these emissions different types of emission reduction technologies and fuels are monitored and considered in the CLINSH project:

- SCR: Selective catalytic reduction is an aftertreatment device that reduces NO_x emissions.
- SCR + DPF: SCR in combination with a diesel particulate filter that reduces PM emissions from exhaust gases.
- Gas-to-liquid fuel (GTL): GTL is a liquid fuel converted from natural gas. GTL can be used as a substitute for diesel and results in lower NO_x and PM emissions compared to diesel.
- Liquified natural gas (LNG): the use of LNG results in lower NO_x and PM emissions compared to diesel. LNG can be used as the single fuel in a monofuel engine commonly used in a gas-electric configuration. Another option is the use of LNG in combination with diesel using a dual fuel engine. In this configuration, the objective is to run mainly on LNG and use diesel only for ignition, but the engine can also fully run on diesel.
- Fuel-water emulsion (FWE): the diesel oil is homogenised with fresh water before injection into the engine. Apart from lowering smoke and soot emissions significantly, the system reduces NO_x levels and CO_2 emissions as well.
- Diesel-electric: rather than using a diesel engine for propulsion, an electric engine powered by generally two diesel generators is used. This system could reduce emissions as this set-up allows the use of the generator sets at a more optimal engine load[1]. In the future batteries can also be used to power the electric motor, replacing the conventional engine and resulting in zero-emissions during operation.
- Stage V/Euro VI diesel engines: Stage V/Euro VI engines are diesel engines with an SCR and DPF integrated. Euro VI engines are originally constructed for the automotive sector and follow corresponding emission standards. As these standards are more strict than current inland waterway standards (CCNR2 and Stage V) there are lower emissions of NO_x and PM compared to regular IWT engines.

1 A large share of the engine power is unused by vessels during normal operation. Only in specific situations and during manoeuvring the engine load is over 80%. In most cases the average load is between 25-50%. Using two generator sets, one of the generator sets can be switched off at low energy demand, allowing the generator set to operate at a more optimal engine load.

Text box 1 – Zero-emission technologies

The technologies monitored in CLINSH focus on the reduction of NO_x and PM_{10} emissions and not (so much) on the reduction of CO_2 emissions. However, since the Paris Agreement, the EU Green Deal, the Mannheim Declaration and most recently the Fit for 55 package, CO_2 reduction in IWT has become an even more important goal. Technologies such as battery-electric engines, hydrogen fuelled engines (either fuel cells or combustions engines) and biofuels are getting more and more attention. Biofuels like FAME have no significant impact on the NO_x and PM emissions, whereas HVO has similar quality and emission performance as GTL. Battery-electric and hydrogen-fuelled vessels have no combustion emissions at all, or much lower emission in the case of H_2 used in a combustion engine.

The zero-emission technologies, however, are not yet well suited for IWT. ZE technologies are currently at the phase where initial pilots are being designed and policy ambitions are formulated. For example, the Dutch Climate Agreement (and accompanying Green Deal) has set a goal of 150 inland ships in 2030 with a zero-emission drivetrain. This is still a very limited number compared to the total of about 9,000 IWT ships in the West-European IWT fleet. Financial and practical restrictions limit large-scale uptake of zero-emission technologies in the short term. Up to 2035, therefore, zero-emission technologies are expected to play a limited role and will only be used for specific short distance trips.

For this reason, zero-emission solutions are not included for the scenario outcomes (both baseline and the CLINSH scenario presented in Chapter 4) as they are not expected to be a widely available suitable option in the short term. Therefore we assume that carbon emission reductions up to 2035 will be mainly the result of increased application of biofuels in regular diesel engines. The use of biofuels does not hamper the functioning of CLINSH technologies. On the contrary, biofuels and CLINSH technologies can support each other in improving environmental performance of inland vessels.

3.2 Method cost-benefit analyses

Action C1 has collected the costs and benefits for each technology based on a literature review and input from the CLINSH fleet monitoring program. The study gives an overview of the social costs of the different technologies, comprising of both the financial costs (investment, operational and maintenance cost) and the external costs of CO_2, NO_x en PM emissions, based on the external cost factors from (CE Delft; INFRAS;TRT;Ricardo, 2019). The external cost factors take into account the damage cost of air pollution (e.g. health costs and costs of crop yield losses) and prevention costs of CO_2 emissions. For every ship category a differentiation was made for low, medium and high fuel consumption (i.e. external cost factors were determined for the 25% lowest consuming ships, the 50% medium consuming ships, and the 25% highest consuming ships).

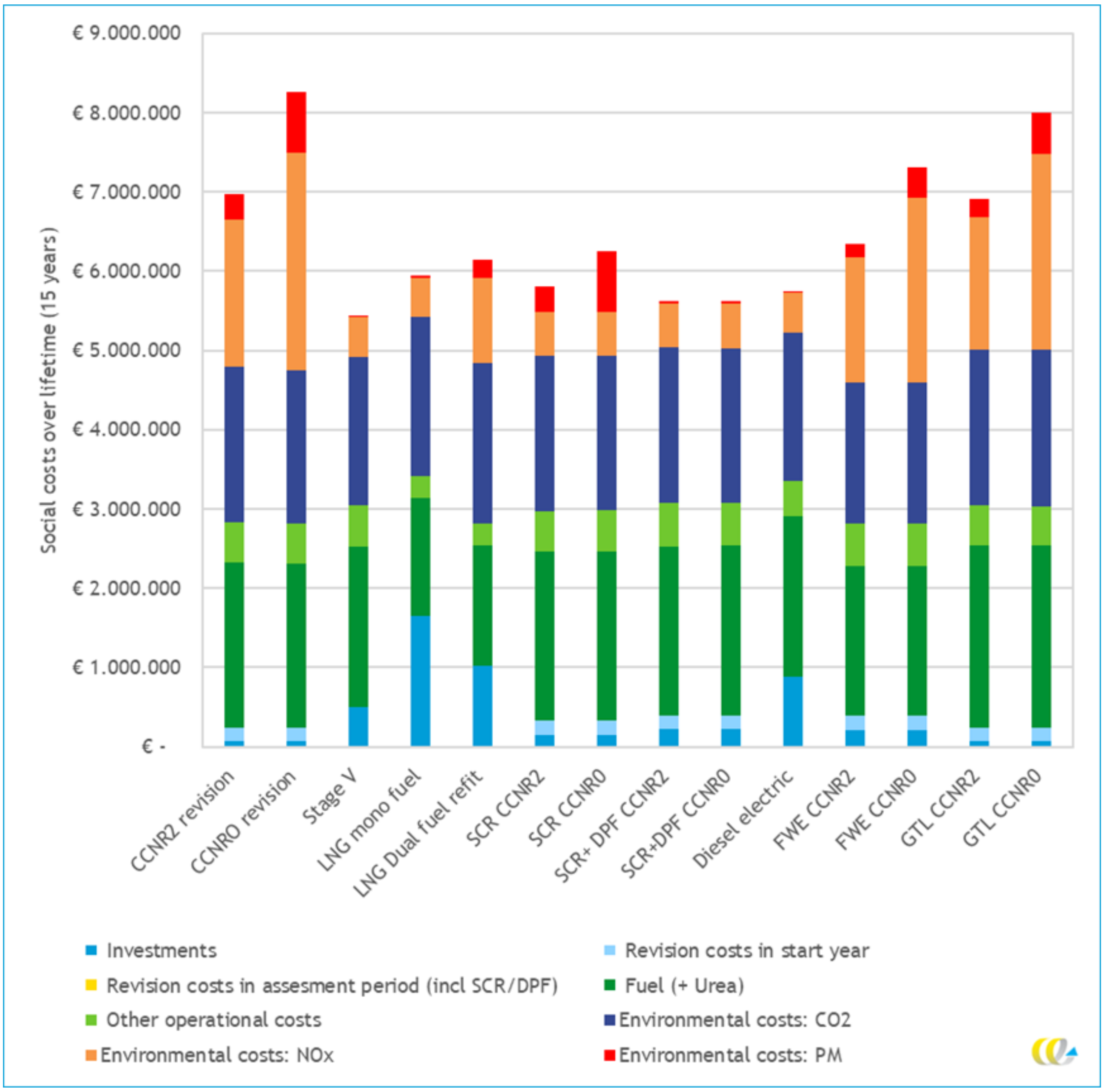
For the different options and fuel consumption profiles, the costs and benefits have been analysed over a period of fifteen years, taking into account, if relevant, repeat investments and revision according to the expected engine lifetime per ship type. The Net Present Value (NPV) method was used to express the total costs over a period of fifteen years, using a depreciation percentage of 4%. As a default option the costs of continuing with the same engine have been analysed.

The costs of the different options are evaluated at the moment engine revision is needed. It has been assumed that all engines will need an engine revision between now and 2035.
Because there are large variations between the different vessel sizes and the types of operational use (e.g. power, fuel consumption), different technologies can be beneficial for different parts of the fleet.

Figure 2 shows the results for the NPV calculations for a dry cargo 86 metres vessel with average fuel use. The highest social costs are found for the revision of the CCNRO engine, while the Stage V engine is the option with lowest social costs. From a vessel owner point of view (excluding the environmental costs which are borne by society) revision of the current engine is the least expensive option, while the social costs of a Stage V engine are among the options with the highest costs. This example amplifies the need for policy intervention in order to reduce the environmental costs from pollutants.

For every ship category, with every ship category differentiated to low, medium and high fuel consumption, the option with the lowest social cost was identified, which in the case of the dry cargo 86 metres vessel with average fuel use, is the Stage V engine.

Figure 2 - Results of NPV calculation for dry cargo 110 metres vessel with average fuel use for a fifteen year timeframe



4 Results CLINSH scenario

The CLINSH scenario focusses on applying measures reducing NO_x and PM_{10} up to 2035. The situation after 2035 is much more uncertain, and options for emission reduction might include new technologies, such as battery-electric and hydrogen fuelled engines.

Vessels autonomously switching to Stage V in the baseline scenario will also be switching to Stage V in the CLINSH scenario as these ships need a new engine. For the remaining vessels, still sailing on traditional combustion diesel engines in the baseline (CCNR2 and older), we assume in the CLINSH scenario that due to new supporting policy, these ships will switch to the option which results in the lowest social costs. The policies that stimulate these choices are discussed in D2.3 and D2.1. For each vessel type, with a differentiation between low, medium and high fuel consumption, the options with lowest social costs are selected for the CLINSH scenario.

It should be noted that other than the change in engine and/or fuel type, the baseline and CLINSH scenario are exactly the same. Both scenarios are built on the same assumptions about fleet size, average vessel sizes, freight market developments, etcetera.

Table 3 shows the results for the CLINSH scenario. The most applied option is the installation of Stage V engines. This is partly due to the autonomous engine renewal (as can be seen in Table 3), and partly because a Stage V engine, in many cases, is the option with the lowest social costs (as shown in Report C1). GTL used by current diesel engines is the second most selected option, especially for small vessels. SCR, SCR + DPF and LNG are selected for a limited number of vessels, partly as part of the existing vessels that were already using these techniques. Revision, diesel-electric, LNG dual fuel engine refit and FWE are options that in no situation lead to the lowest social costs, and therefore these options are not selected for the CLINSH scenario.

SCR + DPF and SCR are options that theoretically could reduce NO_x and PM (with DPF) emissions to the same level as Stage V engines, as these options apply similar reduction technology.
The advantage of a Stage V engine, however, is that the engines have been designed and are obliged to reach the Stage V emission levels, whereas aftertreatment SCR and DPF do not need to reach specific emission levels. The CLINSH fleet monitoring results also show that SCR + DPF aftertreatment can indeed achieve low emissions, but generally does not meet the Stage V emission levels. From a social cost-benefit perspective, the Stage V engines are therefore more cost-effective. The preferred options may be different from the end user perspective as discussed in Deliverable C1.

Table 3 - Number of vessels by technology in 2035 for CLINSH scenario

Fuel	Diesel				LNG	GTL
Engine type Vessel type	Revision (CCR0/ 1 or 2)	Stage V	SCR	SCR + DPF	LNG monofuel	CCR0/ 1 or 2)
Passenger vessel < 250 kW	-	413	-	-	-	108
Passenger vessel 250-500 kW	-	170	50	-	-	6
Passenger vessel 500-1,000 kW	-	21	16	19	-	3
Passenger vessel > 1000 kW	-	230	-	-	-	-
Push boats < 500 kW	-	158	-	-	-	-
Push boats 500-2,000 kW	-	84	-	3	-	-
Push boats ≥ 2,000 kW	-	13	-	0	0	-
Motor vessels < 80 m length	-	1,257	122	-	-	-
Motor vessels dry cargo typical 80 and 86 m ship	-	709	-	25	-	-
Motor vessels dry cargo typical 105 m ship	-	249	-	9	-	-
Motor vessels dry cargo 110 m ship	-	383	-	13	-	-
Motor vessels dry cargo > 130 (135 m ship)	-	232	-	8	-	-
Motor vessels liquid cargo 80-109m length (typical 86 m ship)	-	379	-	13	-	-
Motor vessels liquid cargo 110 m ship	-	547	-	20	12	-
Motor vessels liquid cargo > 130 (135 m ship)	-	172	-	6	-	-
Coupled convoys	-	123	-	5	16	-
Ferry	-	148	227	-	6	237
Tugboat and workboat	-	250	32	122	-	77
Total	**-**	**5,538**	**447**	**244**	**34**	**431**
Grand total	**6,694**					

* The options dual fuel LNG refit, diesel-electric and FWE are not displayed as these options have the lowest social costs for none of the ship categories.

5 Conclusions

In this report we have described how we have developed a baseline and CLINSH scenario for the development of the Northwestern European inland waterway fleet. The baseline scenario gives the development of the IWT fleet without any policy incentives on top of the existing ones. The CLINSH scenario shows how the fleet can develop when the most social optimal engines technique is applied for the fleet.

The IWT fleet and engine characteristics (engine age, lifetime and engine size) for the base year (2015) have been based on the results of the European Horizon 2020 PROMINENT. Starting from this year, we have modelled the effect of autonomous engine renewal based on engine life time and engine age, giving information on the age and type of engines in scenario years 2020 and 2035. On top of engine renewal we have modelled the effects of market development in freight transport developments (e.g. oil and coal) and expected developments in vessel size.

The resulting baseline scenario shows a small increase in transport fleet of IWT towards 2035. The small increase is the result of decreasing demand for oil and coal transport, but increasing demand for container transport and other commodities such as chemical products. In 2020 the majority of engines are unregulated, CCNR1 and CCNR2 engines. In 2035 a considerable amount (75%) of vessels is still using unregulated or CCNR1/CCNR2 engines, but also 25% of the engines is Stage V. For vessel categories with many sailing hours a relatively higher share of Stage V engines will be installed in 2035 as these vessels replace engines sooner. In the baseline scenario, due to the absence of policies, there will be no additional vessels applying technologies that increase end user costs, like SCR + DPF.

In the CLINSH scenario we assume that in the period 2020-2025, due to new supporting policy, IWT vessels will switch to the alternative techniques and fuels that result in the lowest social costs. In the social costs both the total cost of ownership (TCO) and the environmental costs (NO_x, PM and CO_2) are considered. The options considered are SCR + DPF, SCR only, LNG, LNG dual fuel, GTL, FEW, new Stage V (of Euro 6) engines and as engine revision of the existing engine. Battery electric and hydrogen have not been considered as these technologies are not yet mature and are not expected to play a significant role up to 2035. The results on the social costs per ship category from C1 have been applied to construct the baseline scenario.

The most applied option in the CLINSH scenario is the installation of Stage V engines (87% of vessels). This is partly (25%) due to the autonomous engine renewal, but mainly because a Stage V engine, in many cases, is the option with the lowest social costs (as shown in Report C1). GTL used in existing non-regulated, CCNR1 and 2 diesel engines is the second most selected option (10%), especially for small vessels. SCR, SCR + DPF and LNG are selected for a limited number of vessels, partly as part of the existing vessels are using these techniques. According to the results from the C1 study, Stage V engines have low social costs in many cases. SCR + DPF and SCR are options that theoretically could reduce NO_x and PM (with DPF) emissions to the same level as Stage V engines, as these options apply similar reduction technology. The advantage of a Stage V engine, however, is that the engines have been designed and are obliged to reach the Stage V emission levels, whereas aftertreatment SCR + DPF do not need to reach specific emission levels. The CLINSH fleet monitoring results also show that SCR + DPF aftertreatment can indeed achieve low emissions, but generally does not meet the Stage V emission levels. From a social cost-benefit perspective, the Stage V engines are therefore often more cost-effective.

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A Detailed construction of baseline scenario

Step 1: Current fleet

In the first step we have assessed the engine information on the current fleet. No up-to-date and complete dataset exists for European inland waterway vessels. The most complete database is the database from IVR, which is the international organisation for insurance in the inland waterway sector. The IVR database contains most vessels that are sailing on the Rhine and equivalent rivers. However, the dataset is not complete and vessels or vessel information is missing. The European Horizon 2020 PROMINENT project constructed a comprehensive dataset for inland vessels based on the IVR database. Other sources, for example binnenvaart.eu and debinnenvaart.nl, were used to check and complement the data. The PROMINENT dataset presents the results for the year 2015. The output of the PROMINENT project can be found in (Stichting Projecten Binnenvaart, 2016) and in (STC-NESTRA & RebelGroup & EICB, 2015). Based on the output of these reports a composition of the current fleet has been constructed for CLINSH.

The vessel types distinguished in CLINSH can be found in Table 4. The fleet characteristics are based on PROMINENT and the IVR database. The number of vessels from PROMINENT has been corrected based on the number of vessels within each category with active AIS signals in the year 2018 (See Deliverable B3). The AIS signals are measured for Northwestern Europe. Vessels operating solely in other regions, e.g. Eastern Europe or Southern France, are therefore not included. This number of vessels is in line with the emission modelling in deliverable B3. The most observed vessel types are the 38-49 metres cargo vessels and the passenger vessels with less than 250 kW engine power. These vessels are among the smallest cargo and passenger vessels. Vessels with more engine power generally have a higher number of engines installed. For example, cargo vessels over 135 metres have on average two engines for propulsion. The average power installed on these vessels exceeds 2,500 kW.

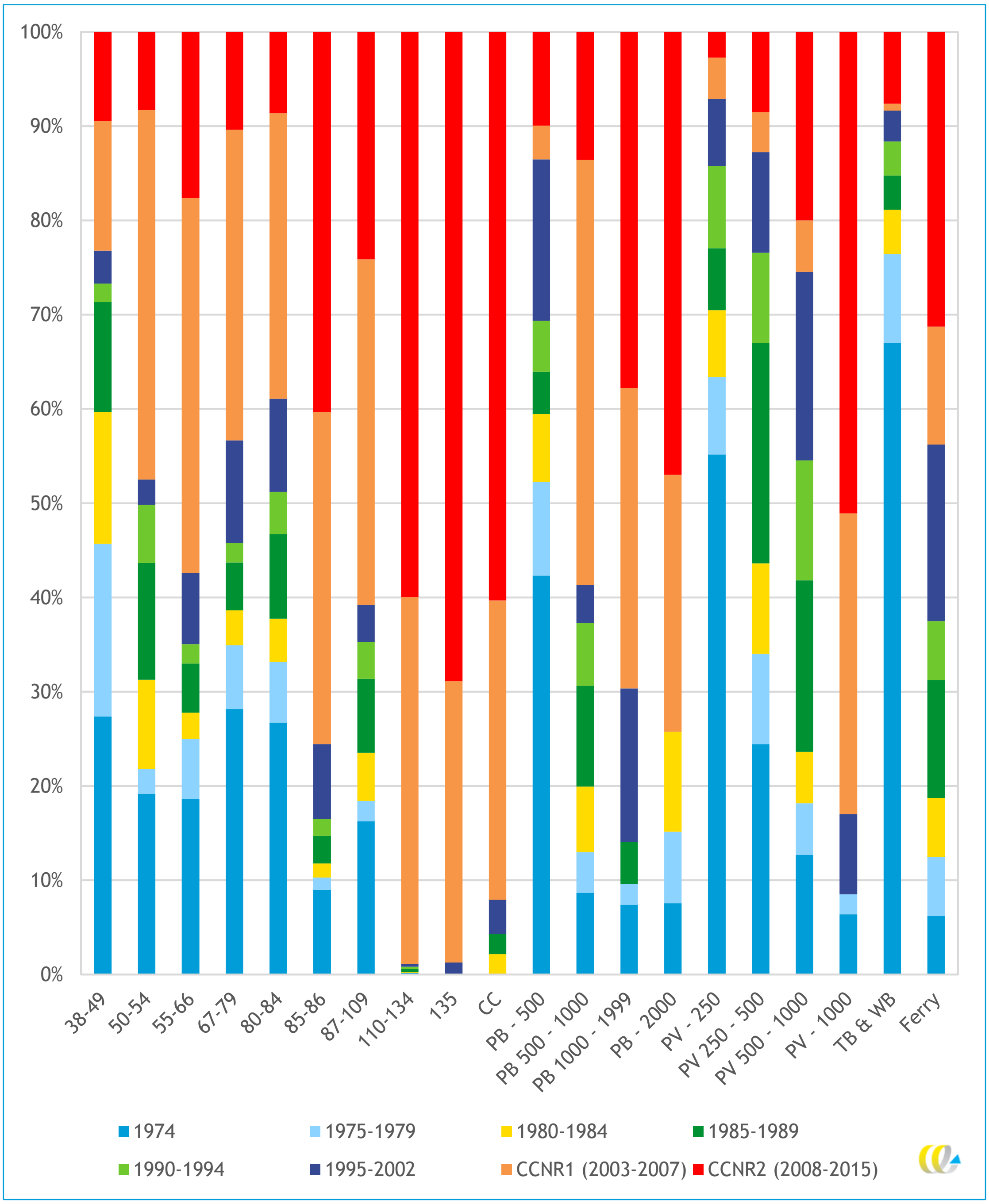
Table 4 - Vessel types and characteristics of inland waterway fleet

Vessel type	Number of active vessels	Number of propulsion engines	Average power (kW)
Cargo vessels			
38-49 metre	763	763	198
50-54 metre	173	181	275
55-66 metre	419	461	388
67-79 metre	484	514	494
80-84 metre	509	568	631
85-86 metre	550	607	841
87-109 metre	273	314	1,059
110-134 metre	922	1,063	1,506
> 135 metre	288	568	2,613
Coupled convoys	143	279	2,237
Push boats			
< 500 kW	155	186	247
500 – 1,000 kW	71	110	677
1,000 – 2,000 kW	21	41	1,396
> 2,000 kW	14	38	3,458
Passenger vessels			
< 250 kW	521	605	126
250 – 500 kW	227	342	429
500 – 1,000 kW	60	109	693
> 1,000 kW	155	370	1,519
Other vessel types			
Tugboat and working vessels	480	600	500
Ferry	618	1,352	644
Grand total	**6,846**	**9,071**	**N/A**

Construction years of engines

The construction years of inland waterway engines in 2015, as inventoried by PROMINENT (Stichting Projecten Binnenvaart, 2016), are shown in Figure 2. These construction years are the starting point for the modelling of autonomous engine renewal. The figure shows that older engines can mostly be found in vessels with the least sailing hours (300-1,300 per year): smaller cargo vessels, small push boats, small passenger vessels and tugboats and workboats. Vessels with many sailing hours (2,000-7,500 per year), for example cargo vessels longer than 110 metres, have mostly CCNRI and CCNRII engines.

Figure 2 - Number of engines by year build by vessel type in 2015



Step 2: Autonomous engine renewal

In the second step we modelled the autonomous renewal of inland vessel engines, starting from the construction years of the engines currently used by inland vessels from Step 1.
By applying the engine lifetimes, a model has been created for the autonomous renewal of engines. This section discusses the assumptions and outcomes for autonomous engine renewal.

The engine lifetime differs between type of vessels and age of vessels. The engine of an inland vessel can be used around 50,000 hours[2]. The lifetime can be further increased by revision of the engine. In line with (STC-NESTRA & RebelGroup & EICB, 2015) we assume that each engine is revised once in its lifetime. For larger vessels this results in a lifetime including revision of about 25 years. For vessels with less sailing hours (approximately below 1,500 a year) the lifetime can be even longer, on average 30 years according to EICB. This is also confirmed by a survey from BLN among 350 vessel owners which showed that about 7.5% of engines are older than 40 years.

From literature we know two extensive models that show the renewal of engines. TNO presents a model that is used for the Dutch emissions calculations (Hulskotte, 2018). This model distinguishes three size classes, is based on a Weibull function and assumes a median lifetime of engines around 15 years. The model results in a small variation between engine lifetimes of beforementioned three different size classes.
STC-NESTRA (2015) presents a model with a larger difference in average engine lifetime in hours between slow, medium and high speed engines resulting in different lifetimes in years per vessel class due to the difference in annual sailing hours. A normal distribution with a standard deviation of 20% of the engine lifetime is applied. Lifetimes before revision range between 50,000 and 75,000 hours depending on the engine type. STC-NESTRA (2015) assumes that every engine is revised once. This results in lifetimes between 15 and 30 years for large vessels, while smaller vessels have engine lifetimes of approximately 60 to 90 years (STC-NESTRA & RebelGroup & EICB, 2015).

Based on a further literature check and discussions with sector experts (EICB, BLN) some drawbacks of both modelling methods came out. The methodology by TNO does not acknowledge the longer lifetime of engines of smaller vessels that on average have an age of at least 30 years according to PROMINENT. Furthermore, according to the model of TNO, 10% of the engines reaches a lifetime of only 5 years, a share which is considered to be too high by the experts.

The higher difference in engine lifetimes between small and larger engines according to STC-NESTRA (2015) is considered realistic given the differences of the average engine age between small and large engines in the current fleet. The average lifetimes of engines, however, is quite high, especially for smaller vessels. (BLN-Schuttevaer, 2017), (Panteia, 2019) and (IFEU, 2019) do not confirm the estimated average lifetimes over 60 years for smaller vessel types.

In CLINSH, we have decided to follow the modelling approach of STC-NESTRA (2015). However, we have limited the average lifetime of engines to a maximum of 60 years. The lifetimes in hours per engine are shown in Table 5. The resulting engine lifetimes per type of vessels are shown Table 6 and Table 7.

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2 Bron: Pon Power, Panteia, STC NESTRA.

Table 5 - Estimated lifetime of engines (including revisions)

	Lifetime of engines (hours)		
Rotational speed class	**< 750 RPM**	**750 – 1,250 RPM**	**> 1,250 RPM**
Engines before 1980	160,000	140,000	120,000
Engines after 1980	127,500	106,250	85,000

Source: Own figures based on (STC-NESTRA & RebelGroup & EICB, 2015) (see text).

Table 6 - Lifetime (years) of engines after 1980

		Engine lifetime (in years)		
Vessel type	**Sailing hours**	**< 750 RPM**	**750 – 1,250 RPM**	**> 1,250 RPM**
Cargo vessels				
38-49 metre	1,900	60	56	45
50-54 metre	1,700	60	60	50
55-66 metre	1,700	60	60	50
67-79 metre	1,800	60	59	47
80-84 metre	1,700	60	60	50
85-86 metre	1,900	60	56	45
87-109 metre	2,400	53	44	35
110-134 metre	2,500	51	43	34
> 135 metre	3,100	41	34	27
Coupled convoys	3,300	39	32	26
Push boats				
< 500 kW	1,420	60	60	57
500–1,000 kW	2,900	44	37	29
1,000–2,000 kW	5,900	22	18	14
> 2,000 kW	8,100	16	13	10
Passenger vessels				
< 250 kW	940	60	60	60
250–500 kW	700	60	60	53
500–1,000 kW	750	53	44	35
> 1,000 kW	1,750	58	48	39
Other vessel types				
Tugboat and working vessels	750	60	60	60
Ferry	916	53	44	35

Source: (STC-NESTRA & RebelGroup & EICB, 2015) & own analysis.

Table 7 - Lifetime (years) of engines before 1980

		Engine lifetime (in years)		
Vessel type	**Sailing hours**	**< 750 RPM**	**750 – 1,250 RPM**	**> 1,250 RPM**
Cargo vessels				
38-49 metre	1,900	60	60	60
50-54 metre	1,700	60	60	60
55-66 metre	1,700	60	60	60
67-79 metre	1,800	60	60	60
80-84 metre	1,700	60	60	60
85-86 metre	1,900	60	60	60
87-109 metre	2,400	60	58	50
110-134 metre	2,500	60	56	48
> 135 metre	3,100	52	45	39
Coupled convoys	3,300	48	42	36
Push boats				
< 500 kW	1,420	60	60	60
500–1,000 kW	2,900	55	48	41
1,000–2,000 kW	5,900	27	24	20
> 2,000 kW	8,100	20	17	15
Passenger vessels				
< 250 kW	940	60	60	60
250–500 kW	700	60	60	60
500–1,000 kW	750	60	58	50
> 1,000 kW	1,750	60	60	55
Other vessel types				
Tugboat and working vessels	750	60	60	60
Ferry	916	60	58	50

Source: (STC-NESTRA & RebelGroup & EICB, 2015) & own analysis.

Rotterdam CCNRII requirement

The port of Rotterdam has announced the introduction of an environmental zone for inland vessels in 2025 (De Raad van de gemeente Rotterdam, 2019). Only vessels with a main engine compliant with at least CCNRII regulation are allowed to enter the port of Rotterdam from 2025 onwards.
This measure is limited to the port basins only thus does not impact the main waterways. Nevertheless, many vessels that visit the port of Rotterdam would have to upgrade to newer engines.[3] Using AIS data we have found that in 2018 about 5,800 inland vessels have visited the port of Rotterdam. Furthermore, like argued in STC-NESTRA & RebelGroup (2015), it is expected that many vessel owners will install a CCNRII motor before the more expensive Stage V engines become mandatory. Based on the fleet characteristics, we have estimated that the Rotterdam environmental zone leads to an increase of installed replacements of about 4,000 engines up to 2021.

3 The city of Nijmegen has announced that it intends to follow the port of Rotterdam's lead. This is however no formalised policy and therefore not included in the modelling.

Step 3: Market developments

In the third step we have investigated the expected freight volume developments and scale increases of inland vessels. These factors influence the supply and demand for specific vessel types. In Step 3a we describe the current situation of freight volumes per freight type and vessel type. In Step 3b expected developments in freight volume are assessed to predict the need for certain vessel types in the future. The market developments are constructed based on the current demand for inland waterway transport and the expected future changes in transport demand. In Step 3c the trend of increasing average vessel capacity is applied to the fleet development.

Step 3a: Current market situation

The current freight volumes transported by inland waterway transport are described in various European and national sources. The sources have been combined to construct a detailed overview of the current freight volumes by vessel type. The level of detail of these sources differs, i.e. some sources distinguish between product types whereas others do not. The following sources and information have been used:

- Total freight volumes and the volumes per type of goods based on NST2007[4] categories of inland waterway transport in Northwestern Europe obtained from Eurostat. This information has been cross-checked with information from national statistical agencies (Belgian[5] and German), which turns out to be well in line with each other. Over 90% of the freight volume is in Germany, Belgium and the Netherlands.
- The Dutch inland waterway model BIVAS provides information on the type of goods transported by the various vessel types based on NSTR categories[6]. This information has been used to identify the freight volumes per freight type and to distribute the type of goods over the vessel types.

To create an overview of goods per NSTR freight category, first the German and Belgian data have been converted to NSTR categories with a conversion table used for Belgium road transport modelling[7]. Table 8 shows the resulting transport shares in Germany and Belgium next to the shares of transported goods in the Netherland from BIVAS. The Northwestern European average distribution was estimated by weighing the distribution with the tonnes of freight in Germany, Belgium and the Netherlands.

4 Standard goods classification for transport statistics abbreviated as NST (2007).

5 Statbel (Algemene Directie Statistiek - Statistics Belgium) ttbe_fr_ingds_ton.

6 Classification of good (Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée).

7 Departement Mobiliteit en Openbare Werken (2019).

Table 8 - Freight shares per country in 2018

	Netherlands	Germany	Belgium	Average N-W Europe
Agricultural products and live animals	4%	6%	5%	5%
Food and animal fodder	6%	6%	5%	6%
Solid mineral fuels	9%	17%	8%	11%
Petroleum products	14%	15%	6%	12%
Ores and metal waste	10%	13%	11%	11%
Metal products	3%	4%	6%	4%
Crude and manufactured minerals, construction materials	26%	10%	13%	18%
Fertilisers	2%	11%	10%	7%
Chemicals	13%	7%	5%	9%
Machinery, transport equipment, manufactured articles and miscellaneous articles	13%	11%	32%	17%
Total freight volume (Mtonne)	**359**	**198**	**205**	**N/A**

Source: own analysis based on (Eurostat, 2020).

The results show a relatively high share of coal transports for Germany. The absolute quantity is comparable with the Netherlands, as most coal is transported from Dutch seaports. In the Netherlands high volumes of construction materials and crude and manufactured minerals are transported. In Belgium many containers are transported by inland waterways.

Finally, the information in BIVAS on the tonne share of different vessel types in a certain freight category (NSTR categories) has been applied to the total European transport volumes per freight category, as information on the distribution over vessel type is not available for other European countries. Figure 3 (right side) shows the type of freight transported by vessel type in 2018. Most freight (in volume) is transported by vessels between 110-134 metres and vessels longer than 135 metres. These are, not surprisingly, the vessels with the largest capacities. The vessels with the smallest capacities carry much smaller amounts of freight. Petroleum products and chemical products are mainly carried by the larger category vessels. Coal and ores are often transported by push boats. Other goods, which includes containers are mainly transported by large cargo vessels. Crude and manufactured minerals, building materials (i.e. sand and stone) are transported for a large share by the smaller vessel types.

Figure 3 - Freight volumes and categories by vessel type in 2018

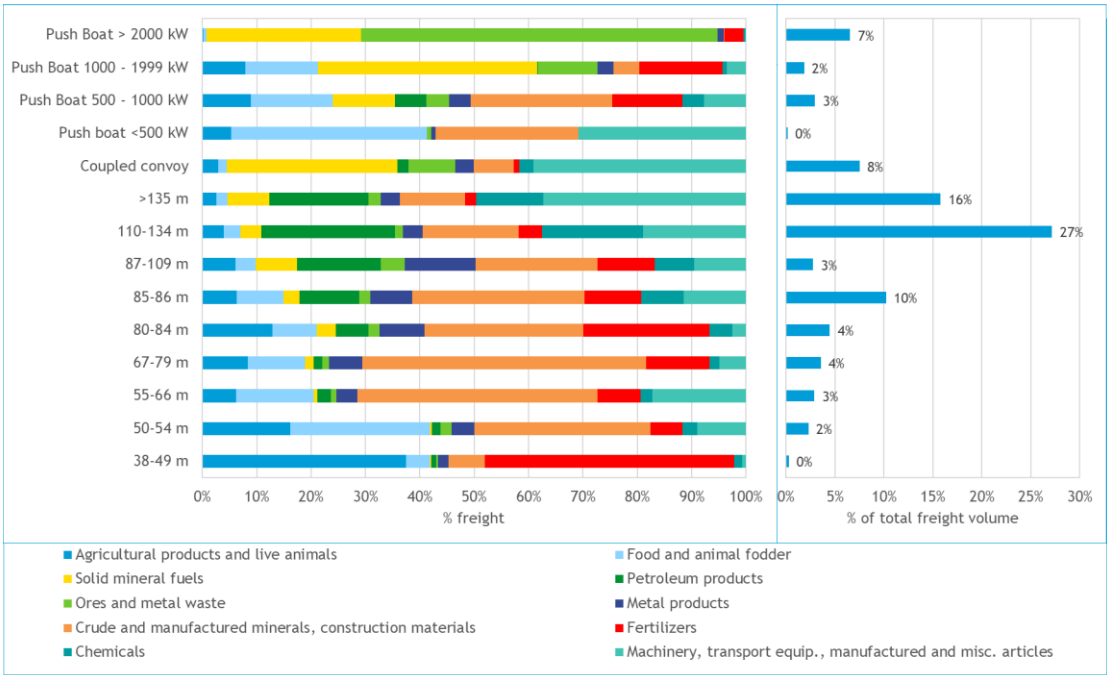


Figure 3 (left side) shows the type of goods transported by vessel type relative to the total volume of goods per vessel type. The vessels between 38-49 metres mostly transport agricultural products and fertilisers. The slightly larger vessels between 50 and 109 metres are used more for crude and manufactured minerals and building materials. The larger cargo vessels also transport more chemicals, petroleum products and machinery, transport equipment and containers. Coupled convoys and larger push boats transport solid mineral fuels. The largest push boats are specialised in transporting ores and metal waste. Smaller push boats transport food and animal fodder as well as crude and manufactured minerals.

Step 3b: Expected volumes

The demand for inland waterway transport until 2030 depends on the demand for goods transported by inland waterways. The demand for certain goods, for example coals and petroleum products, is expected to decline due to decarbonisation of the economy. Demand for other goods, for example containers and chemicals is expected to increase due to higher economic development. Several sources predict the development of demand for inland waterway transport. Short-term predictions are made in more detail compared to long-term predictions. Therefore short and long-term developments are distinguished.

Short term

The short-term developments are discussed by several sources. Panteia has made predictions for the Netherlands until 2022 (Panteia, 2018). The development of transported tonnes of various cargo types are considered. Certain vessel types and transport performance (tkm) are also discussed in the report. Panteia expected an annual growth of 1.6% for the Dutch inland waterway market between 2016 and 2021. Intraplan Consult & BAG-luftverkehr (2019) predict the short-term development for the German market until 2022 and provides the volume and transport performance of several cargo types. For Germany a reduction of 4% in transported tons is expected in 2022 compared to 2017, the reduction in transport performance is slightly higher. The Dutch institute for mobility (Kennisinstituut voor Mobiliteitsbeleid (2018)) predicts the short-term growth of the inland waterway transport market until 2023. A growth of about 5% compared to 2017 is expected.

The Dutch and German predictions for product types have been combined to establish an expected annual growth figure per product type for the larger Rhine region. The expected growth is weighted based on transport volumes in Germany and the Netherlands.
The resulting annual growth factors per product type are shown in Table 9. Short-term growth is expected for liquid petroleum products, ores and metal waste as well as machinery and containers. Solid mineral fuels and food are the only product type where large declines in transport volumes are expected. This is a consequence for the recently announced closures of German coal-fired power plants, for which we have adjusted the decline. The transport of other product types is more or less stable between 2018 and 2022.

Table 9 - Short-term growth per product type

Product type	Annual development 2018-2022
Agricultural products and live animals	100.1%
Food and animal fodder	97.1%
Solid mineral fuels	96.0%
Petroleum products	99.0%
Ores and metal waste	102.5%
Metal products	99.9%
Crude and manufactured minerals, building materials	100.4%
Fertilisers	100.0%
Chemicals	100.1%
Machinery, transport equipment, manufactured articles and miscellaneous articles	103.0%

The growth rates result on average in a 1.4% higher freight volume as compared to 2017, which is in the middle of the range of the earlier mentioned sources. This corresponds with an annual growth of 0.27%.

COVID-19

The main research for this report has been carried out before the start of the COVID-19 crisis. As a consequence effects of the COVID-19 crisis on inland waterway transport demand are not considered. The long-term effects of the crisis are expected to be small, as is discussed by (EC, 2020). We have decided not to adjust the analysis in order to include effects of the COVID-19 crisis. The effects are minimal and altering the calculations would result in delays and problems for other tasks within the CLINSH project.

Long term

For the long-term predictions several sources are used. The Dutch infrastructure manager has made predictions about long-term growth of inland waterway transport in the Netherlands (Rijkswaterstaat, 2017). Two scenarios are used in this study. The annual growth of transport volumes is expected to range between 0.5 and 1%. The Federaal Planbureau & FOD Mobiliteit en Vervoer (2019) predicts a growth of 1.16% in Belgium between 2017 and 2040. Umweltbundesamt (2018) predicts an annual growth of 1.06% of inland waterway transport between 2020 and 2035 in tonkm. Several sources (Panteia, 2018; Intraplan consult GmbH & BAG-Luftverkehr, 2019) show that a close relation exists between freight volume (tons) and transport performance (tonkm). Therefore a similar growth level is presumed for transported tons in Germany. The growth rates for inland waterway transport volumes in individual nations thus range between 0.5 and 1.1%.

The predictions for the Dutch market (Rijkswaterstaat, 2017) provide some indication of the long-term development of cargo types as well. The long-term growth rates per product type have been based on this source. However, the figures for solid mineral fuels and petroleum products have been adjusted according to figures from (TNO, CE Delft, 2020) and (RHDHV, 2019), taking into account the expected decline in coal and fossil fuel use. The resulting growth rates are shown in Table 10.

Table 10 - Annual growth rates between 2018 and 2050

	Short term (2018-2022)	Medium term (2023-2030)	Long term (2031-2050)
Agricultural products and live animals	100.1%	100.8%	100.8%
Food and animal fodder	97.1%	100.5%	100.5%
Solid mineral fuels	96.0%	95.0%	91.0%
Petroleum products	99.0%	98.0%	97.0%
Ores and metal waste	102.5%	100.0%	100.0%
Metal products	99.9%	102.3%	102.3%
Crude and manufactured minerals, building materials	100.4%	99.9%	99.9%
Fertilizsers	100.0%	100.5%	100.5%
Chemicals	100.1%	101.1%	101.1%
Machinery, transport equipment, manufactured articles and miscellaneous articles	103.0%	101.8%	101.8%

Source: (Rijkswaterstaat, 2017), with adjustment for solid mineral fuels and petroleum products based on (TNO, CE Delft, 2020) and (RHDHV, 2019).

Three product groups show long-term growth: metal products, chemicals and marchinery and containers. Due to decarbonisation of the economy the transport of liquid and solid mineral fuels is decreasing. The transport of solid mineral fuels currently mainly exists of coal from Dutch seaports for the German industry. The closure of German coal power plants has been decided by the German government[8]. The last coal power plant will close in 2038 resulting in at least a 60% decrease of transport of solid mineral fuels between 2022 and 2050. The expected decline of fossil fuel transport

8 www.cleanenergywire.org/factsheets/spelling-out-coal-phase-out-germanys-exit-law-draft

results in lower growth rates compared to the national sources. Between 2020 and 2030 the annual growth rate is 0.18% while between 2020 and 2050 the annual growth rate is 0.31%.

Passenger transport

The growth rates of passenger transport have been discussed to a lesser extent. CCNR discusses the recent development of the passenger transport market (CCNR, 2018) and shows that the market has expanded recently, especially for river cruises. (Rijkswaterstaat, 2017) predicts a growth of passenger vessels over 110 metres, which are generally used for river cruises between of 38% up to 55% in 2050 compared to 2014.

Conclusions

The transport of solid mineral fuels has already started to decrease and will continue to decrease in the medium and long-term. Liquid mineral fuels volumes will start to decrease in the medium and long-term due to carbonisation of road transport among others. Growth areas are metal products, containers and chemicals. These predictions result in a slight increase in total transported volumes by IWT.

Step 3c: Vessel size increases

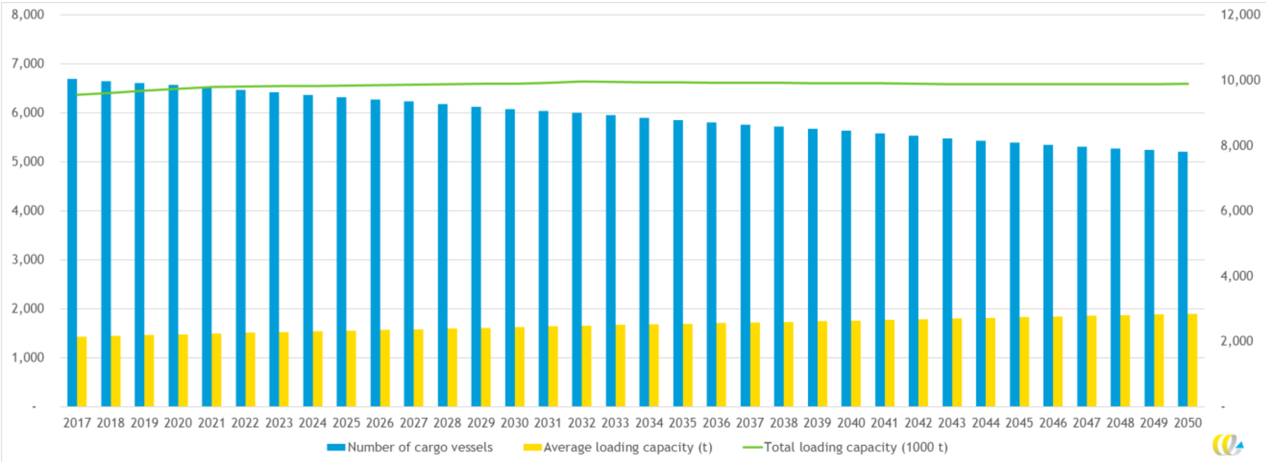
Besides developments in transported volumes, the development in average vessel size has a large influence on the inland waterway fleet. The number of vessels has decreased steadily since 2006 as shown by (CCNR, 2018). At the same time the total combined loading capacity of the IWT fleet has remained constant since 2010 as a result of larger vessels entering the market. The average loading capacity of inland vessels has increased.

From discussions with stakeholders it follows that the scale increases are expected to continue. As a result the number of smaller vessels will decrease while more large vessels will enter the market. Based on the historical analysis by (CCNR, 2018) the following predictions for the future development are made:

- The number of dry cargo vessels has decreased from 8,400 to about 7,000 in just over ten years time. The total loading capacity increased between 2005 and 2009, but remained more or less stable since 2010. This trend is expected to continue.
- The number of tanker vessels has decreased since 2010 from about 1,700 to about 1,500 in 2017. The total loading capacity in the meantime remained equal. This trend is expected to continue.
- The number of push and tug vessels is on the same level in 2017 as it was in 2005. No scale increases are assumed for push and tug vessels.

The assumptions above result in scale increases of the inland cargo fleet. Figure 4 shows how we have modelled this development of the inland waterway cargo fleet towards 2050. The total number of vessels is decreasing due to increase of average loading capacity. The total carrying capacity is assumed to remain constant. This effect has been modelled on top of the market developments under Step 3b.

Figure 4 - Development of scale increases



For passenger transport, the number of passenger vessels longer than 110 metres is assumed to grow (Rijkswaterstaat, 2017). The number of vessels is expected to be 30% larger in 2030 compared to 2017. In 2050 the number of large passenger vessels will be almost 50% higher compared to the number of large passenger vessels in 2017. The number of smaller passenger vessels is expected to remain constant between 2017 and 2050.

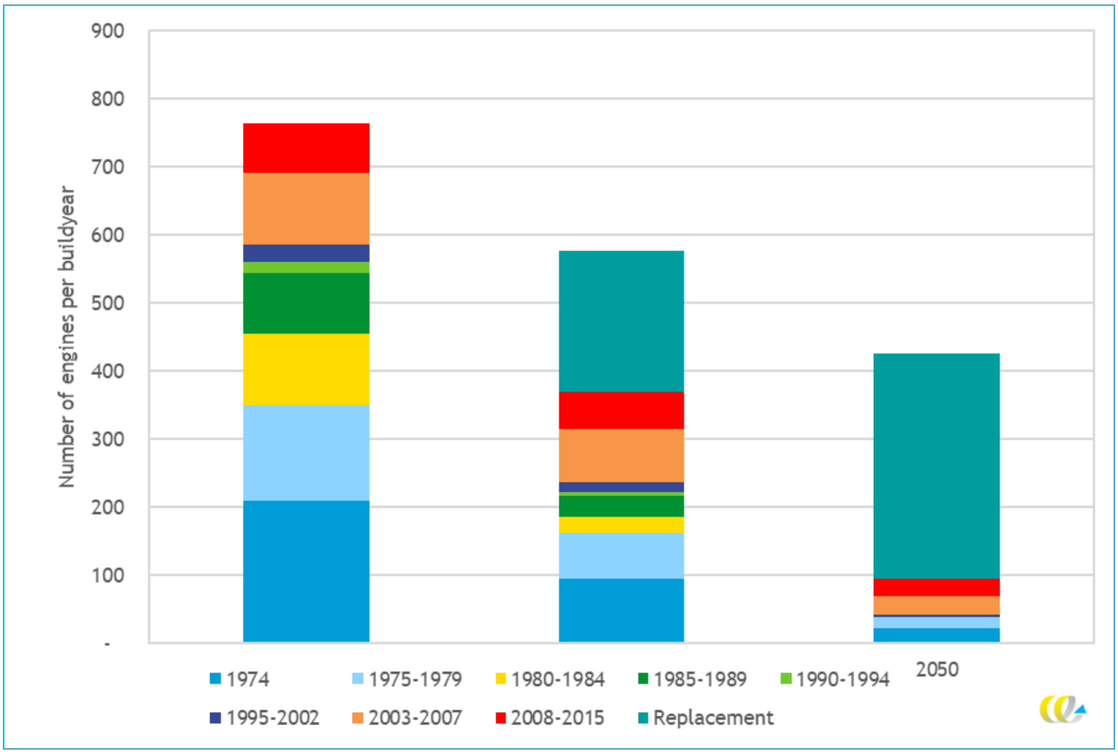
Step 4: Development in number of engines

In Step 4, we have combined the results from the previous steps:

- Step 2 has provided the autonomous development of engines used by various types of inland vessels.
- Step 3 has resulted in the expected development of various types of inland vessels due to market forces and scale increases.

Combining the results in a large database which contains the number of engines per vessel type by year of build between 2015 and 2050. As an example the result for vessels between 80 and 84 metres is shown in Figure 5. The figure shows that the number of engines decreases from 1,400 to about 800 in 2050 due to market forces and scale increases. At the same time a lot of engines are being replaced for newer models. In 2030 20% of the engines will be replaced while in 2050 about 60% of the engines is replaced.

Figure 5 - Number of engines for vessels between 80 and 84 metres



The number of engines per vessel type is shown Figure 7. Overall there is a small decrease in the number of engines between 2015 and 2050. The number of engines in vessels below 85 metres is decreasing, while the number of engines in larger cargo vessels is increasing. The number of engines in large passenger vessels increases.

Figure 6 - Number of engines per vessel type

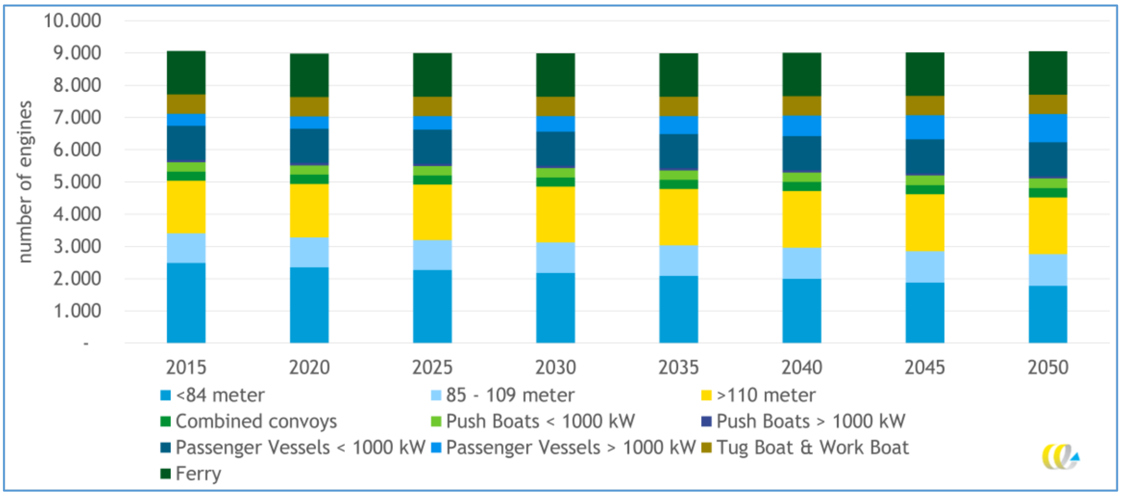
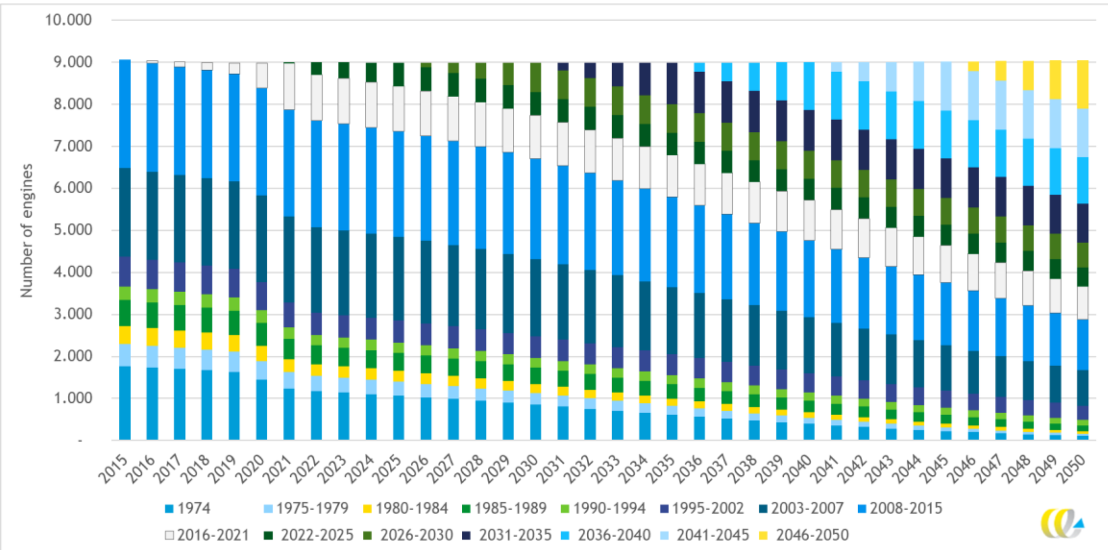


Figure 7 shows the number of engines by construction year between 2015 and 2050. The number of original engines is decreasing between 2015 and 2050. A relatively large share of the larger vessels has new engines, as they are replaced more often due to the higher number of sailing hours (not shown).

Figure 7 - Number of engines by year of build



Step 5: Number of vessels

In the final step the development of the number of engines is combined with the average number of engines by vessel in order to provide data on the number of engine technologies by vessel. Traditional combustion engines are categorised according to CCNR and Stage V emissions standards. These categories are chosen because of their relevance for the cost-benefit analyses. Furthermore emission reduction technologies currently installed in the fleet are also included. Based on a discussion with the EICB we include thirteen vessels sailing on LNG and an (estimated) 100 vessels that have installed SCR + DPF. There are also about 200 or 300 vessels that have installed diesel-electric engines. These engines are not shown separately but are included under CCNR2 engines, as we do not know the specific ship classes. The results for 2020 are shown in Figure 8.

Figure 8 - Number of vessels in 2020

Fuel	Diesel					LNG
Engine type Vessel type	Unregulated	CCNR1	CCNR2	Stage V	SCR + DPF	LNG monofuel
Passenger vessel < 250 kW	458	23	40	-	-	-
Passenger vessel 250-500 kW	191	10	26	-	-	-
Passenger vessel 500–1,000 kW	44	3	13	-	-	-
Passenger vessel > 1,000 kW	25	49	86	-	-	-
Push boats < 500 kW	118	6	32	-	-	-
Push boats 500-2,000 kW	14	30	41	-	3	-
Push boats ≥ 2,000 kW	0	0	12	-	-	-
Motor vessels < 80 m length	797	452	376	-	-	-
Motor vessels dry cargo typical 80 and 86 m ship	293	235	142	-	24	-
Motor vessels dry cargo typical 105 m ship	55	90	94	-	8	-
Motor vessels dry cargo 110 m ship	3	187	164	-	12	-
Motor vessels dry cargo > 130 (135 m ship)	3	85	122	-	7	-
Motor vessels liquid cargo 80-109 m length (typical 86 m ship)	61	98	197	-	13	-
Motor vessels liquid cargo 110 m ship	4	148	336	-	18	10
Motor vessels liquid cargo > 130 (135 m ship)	1	34	126	-	6	-
Coupled convoys	5	41	86	-	5	1
Ferry	335	76	195	-	-	6
Tugboat and workboat	413	3	64	-	-	-
Total	**2,819**	**1,571**	**2,155**	**-**	**96**	**18**
Grand total	**6,657**					

Robustness of the results

The results for the baseline scenario modelling are based on several specific assumptions for factors where concrete evidence is not available. We have carried out extensive research for this study, but still several uncertainties remain that influence the baseline scenario results. This section discusses the most important uncertainties and the subsequent assumptions required to overcome the lack of evidence.

One of the most important modelling parameter is the year of build of the engines used by inland vessels. It is well known that engines used in the IWT sector have a long lifetime. The exact year of build of inland waterway engines is, however, uncertain and not well investigated. The construction years of engines in this study are based on the PROMINENT study, that has used various sources. However, as stressed by PROMINENT, the engine data from the main source, the IVR database, is often outdated as vessel owners are not required to update engine information after installation of a new engine (Stichting Projecten Binnenvaart, 2016). PROMINENT has performed multiple checks to check and correct the IVR database. Ultimately engine related information has been provided for around 75% of the vessels. This is a major improvement to the original data available in the IVR database. However, the results still mainly depend on self-reporting of vessel owners and uncertainties towards the exact construction years of engines remain.

Another uncertainty related to the engine year of build is the limited information about the lifetime of engines. The engine lifetime has a great effect on the number of engines available for retrofitting. As discussed, TNO and STC-NESTRA have both presented a model for the renewal of inland vessel engines, with large differences in engine lifetimes, especially for smaller vessels. Whereas STC-NESTRA relates engine lifetimes to sailing hours, TNO does not. Several sources show that longer lifetimes are seen for especially smaller vessels. In practice it is hard to model the behaviour of vessel owners, as often engines can be kept running by revising the engine. Depending on regulatory requirements and investment costs vessel owners will decide to revise existing engines or invest in a new engine.

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