POLICY SUPPORT DOCUMENT

CLINSH

Sustainable waterway transport, clean air

CLean INland SHipping

The purpose of this document is to provide EU, CCNR, national, regional and local policy makers with information about real-world performance, costs and local air quality impacts of emission reduction, fuel transition and onshore power supply technologies for the inland waterway transport (IWT) fleet. Policy makers may use the results of the CLINSH project for developing new legislation and non-regulatory actions to reduce emissions of the existing IWT fleet.

Project:	CLINSH – **CL**ean **I**nland **SH**ipping
Goal:	The objective of CLINSH is to improve air quality in urban areas situated close to ports and inland waterways, by accelerating IWT emission reductions.
Project reference:	LIFE15 ENV/NL/000217
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Glossary

Abbreviation	Meaning
AFIR	Alternative Fuels Infrastructure Regulation
AIS	Automatic Identification System for vessels
CCNR	Central Commission for the Navigation of the Rhine
CCNR1/CCNR2	Emission standards for inland waterway vessels
CLINSH	Clean Inland Shipping, LIFE+ project
DPF	Diesel particulate filter, to reduce particulate emissions
Euro VI	European emissions standard for heavy duty road vehicles (Regulation: 595/2009)
FWE	Fuel water emulsion
GTL	Gas-to-Liquids, a synthetic diesel oil made from natural gas
HVO	Hydrotreated Vegetable Oil, a biofuel for diesel engines
IWT	Inland waterway transport
kW	Kilowatt
kWh	Kilowatt-hour
kton	Kiloton
LNG	Liquefied Natural Gas
NO_x	Collective term for nitrogen oxides (NO, NO_2 and NO_3), emissions of which lead to smog formation, environmental acidification and respiratory damage
OPS	Onshore Power Supply, or shore power for vessels at berth
PM	Particulate matter
$PM_{2.5}$	Particulate Matter smaller than 2.5 micro-metre
PM_{10}	Particulate Matter smaller than 10 micro-metre
SCR	Selective Catalytic Reduction, an exhaust gas treatment system to reduce NO_x emissions.
Stage IIIA	European emission standards for non-road mobile machinery (NRMM), such as construction equipment, railroad engines, inland waterway vessels, and off-road recreational vehicles. (Regulation: 2004/26/EC)
Stage V	Updated European emission standards for non-road mobile machinery (NRMM), such as construction equipment, railroad engines, inland waterway vessels, and off-road recreational vehicles. (Regulation: (EU) 2016/1628)
TCO	Total Cost of Ownership (or Operations)
tkm	Tonne-kilometre: unit of transport performance expressing transport of one tonne over one kilometre
ZE	Zero emissions

1. Main takeaways

1. The CLINSH project has delivered the **first comprehensive estimate of IWT emissions and reduction opportunities** based on real-life emissions measuring and of vessel movement monitoring in West-Europe. Also, the air quality in Duisburg, Europe's largest inland port, and another large inland port was studied in-depth with regard to NO_2 pollution. CLINSH developed emission factors to model the emissions and air quality effects of changing fleet compositions (scenarios). The complete methodology is available for port authorities, local and regional authorities to assess the effect of measures for greening of IWT and to answer policy questions.

2. There is a potential discrepancy between the policy measures for climate change mitigation and air quality improvement, in the short term at least. While future technologies should evidently be zero emission, CLINSH calls for a transitional period to invest in readily available measures for the existing IWT fleet that improve air quality (mainly NO_x) in the short term, although with limited effect on greenhouse gas emissions unless biofuels are applied.

3. The "CLINSH scenario" shows that these investments have a significantly **higher societal benefit (€4.9 billion) than the technical investment costs (€1.3 billion) and the additional total costs for ship owners (€0.76 billion)** as compared to the Baseline scenario. These investments therefore make sense from a socio-economic viewpoint and should be encouraged while developing and introducing zero-emission solutions that improve air quality and also mitigate climate change in the longer term.

4. The preferable options from a societal point of view (social cost-benefit analysis) do not correspond with the preferred options from the individual entrepreneur's perspective (investments and total cost of ownership). The challenge lies in synchronizing the societal and individual interests. This requires **policy intervention through investment support to ship owners** and / or **differentiated tax schemes that support low emission technologies**, in order to reduce the environmental costs from pollutants and to enable and to motivate ship owners to opt for better solutions.

5. CLINSH developed the following policy recommendations to reduce emissions of the existing fleet:

   A. **Promote accelerated deployment of already available technologies to reduce NO_x and PM emissions** until zero-emission technologies based on electric propulsion mature and are supported by a regulatory and incentive framework. By 2035, a mix of technologies will most likely be in use.

B. The socio-economic analysis shows that Stage V (including marinized Euro VI) engine renewal is **optimal from a societal perspective** for many ship types in the next 10-15 years. The relatively high investment costs for Stage V engines are partly compensated by improved fuel efficiency and low emissions as demonstrated for the Euro VI engines in the monitoring fleet. SCR-DPF (with lower investment costs than engine renewal) and GTL (especially for smaller vessel types with lower fuel consumption) also score well. **An incentive scheme should make at least Stage V, SCR-DPF, Fuel Water Emulsion and GTL attractive for the entrepreneurs to invest in.**

C. The EU and Member States should provide incentives for this accelerated adoption through an IWT **Greening Fund or grant schemes**, both for zero emission technologies and short-term air quality abatement options. Ship owners who use clean technologies or fuels could receive a reduction or exemption on the existing waste disposal charges. Budget for the fund or grant schemes could be raised by allocating revenue from the taxation of IWT fuels that is proposed in the Energy Tax Directive. A levy on the fuel, similar to the CDNI regulated waste disposal charge paid by vessel operators when bunkering, but differentiated to the emissions performance of the vessel, could also be considered.

D. The monitoring demonstrates that it is possible to reach the Stage V emission limits with retrofit after-treatment technologies and alternative fuels under real-life sailing conditions, however this requires optimal management of the systems. The performance of after-treatment technologies **should therefore be monitored** to ensure that they work well **in practice**.

E. The widespread adoption of Stage V (equivalent, including marinized Euro VI) engines and optimised after-treatment systems could be stimulated by applying the **Stage V (equivalent) emission standard to the** existing **fleet in 2035.** This can only be achieved when the proposed Greening Fund is in place. It would also increase the effectiveness of such Fund because ship owners will have an additional rationale to re-motorise before 2035, while not precluding the adoption of zero emissions technologies when these become widely available from 2030 onwards.

F. In order to reduce CO_2 emission reductions along with NO_x and PM emissions, CLINSH also endorses the development of **policies for accelerated uptake of biofuels and (sustainable hydrogen based) e-fuels** in IWT fleets. HVO/GTL blends or in future e-fuels/GTL blends may be attractive for shipowners, as those blends would make the price difference to diesel smaller than with 100% HVO or e-fuels.

G. CLINSH also endorses **policies for promoting Zero Emissions technology**. A target of zero-emissions IWT in 2050 is ambitious considering that the technology is not yet mature. Zero emissions technology can be a mainstream option after 2035 and should be stimulated once market-ready. However, in order to achieve short-term air pollutant emissions reductions, Stage V engine renewal and retrofit of after-treatment technologies merit support in the meantime.

h. Given the scarce capital availability in the IWT sector it is recommended to seek permission to provide **investment support up to 80%** over the price difference befitting State aid laws conform with the EU taxonomy, combined with low-interest loans.

i. **Local regulations** can help make the transition via lower emission technologies towards Zero Emissions. Aligned with financial support for engine renewal until 2035 (Greening Fund) and ahead of the proposed Stage V (equivalent) emission standard for the existing fleet in 2035 could be implementation of **low emission zones in ports**. This could be succeeded by zero emission zones in ports in 2050 for instance. CLINSH recommends investigating the feasibility and impact of such zoning.

j. **Emission labelling** may be used as the basis for local regulation of IWT vessels. Using input from the CLINSH consortium, the Netherlands have developed an emission labelling method that rates both air pollutant and climate emissions. This so-called Binnenvaart Emissielabel [1] (IWT emission label), launched on 15 November 2021, could be used for differentiating port dues and for environmental zoning. The aim is to have the labelling method applied across Europe.

k. **Real-life measuring on inland vessels** has provided useful information on the performance of greening technologies. It was demonstrated that they can reach their full reduction potential if well-managed, but in some situations suboptimal results were reached. The experiences in the CLINSH monitoring campaign show that basing vessel regulations on real-life emission measurements rather than fixed emission standards needs **further investigation**, because the measuring campaign has revealed practical challenges. Similar to road vehicles, a periodic measurement of the exhaust gas values could be considered as part of mandatory vessel inspections.

l. Invest in onshore power supply (OPS) where **air quality and/or noise concerns are most pressing** and where the cost effectiveness of euros spent to reduce emissions is highest. The top-3 type of locations are river cruise berths, waiting docks and overnight mooring, tanker berths.

m. The introduction of an **EU-wide permanent tax exemption for OPS** in accordance with Article 15 of the proposal for a reviewed Energy Taxation Directive (COM) (2021563 final) would encourage the deployment and use of OPS based on the strict requirements in AFIR and FuelEU Maritime. Such an exemption would also level the playing field in the maritime sector as the fuel used for onboard generators is today also untaxed.

n. CLINSH also recommends developing **funding mechanisms** to realise OPS in at least Core and Comprehensive ports. Strategies should make sure that current and planned OPS infrastructure in ports could become a stepping-stone for future expanded power infrastructure needed to achieve the Zero Emission ambition for 2050.

1 www.binnenvaartemissielabel.nl, from 15 November 2021

2. Outline of the CLINSH project

2.1 AIMS AND ACTIVITIES

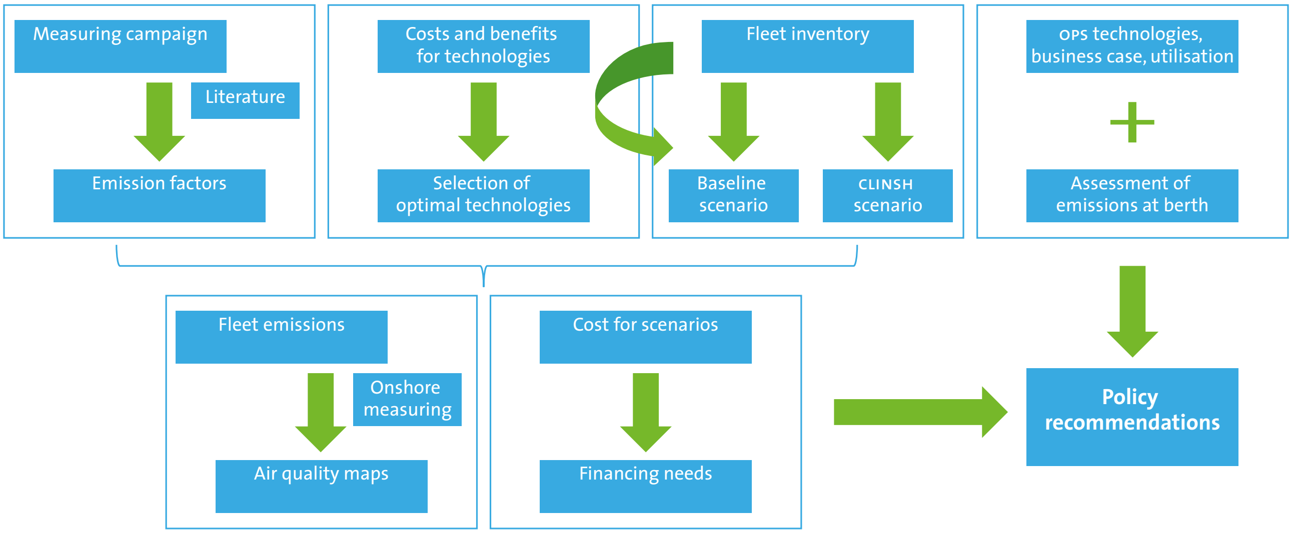
Inland shipping is an efficient way of transport especially for heavy bulk goods such as coal, sand and stone, petroleum products, and also for containers. The efficiency is reflected in a relatively low energy consumption figures per tonne-kilometre (tkm) of IWT as compared to road transport. Air polluting emissions of IWT can also be considerably better than for road transport if available clean technologies and fuels are adopted. [2] If all external impacts are taken into consideration, the average environmental costs per tkm for inland waterways transport are about 60% of the average environmental costs of transport by truck. [3]

Engine emission standards have allowed relatively high emissions of IWT engines until the introduction of the new Stage V emission standard for new engines from 2019 on. Also, engines in IWT have a long lifetime of tens of years and are on average much older than engines in road transport. As a consequence, there are still many engines in the IWT fleet with no emission regulation at all. This is in strong contrast with road trucks, where the average age of trucks in the European Union is 13 years and a large part of the existing fleet already meets the latest Euro VI emission standard. [4]

CLINSH tested and monitored in real life 9 emissions reduction technologies on 43 ships over a 18-24 months period in order to provide policy makers with information about real-world performance, costs and local air quality impacts of emission reduction and fuel transition. These ships were contracted after public procurement. The costs of investing in and operating these technologies have been evaluated, as well as skippers' experiences, as part of this campaign. Figure 1 shows the logic of activities in the project (numbers refer to the chapters in this document).

2 References: UBA (2019), EEA (2021)
3 Impacts of habitat damage, emissions, noise, accidents, calculated by CE Delft, INFRAS,TRT & Ricardo (2019), Handbook on the external costs of transport, Delft: CE Delft,
4 ACEA (1 February 2021)

Figure 1: Core activities of the CLINSH project. Numbers refer to the chapters in this Policy Support Document.



2.2 METHODOLOGY: REAL-LIFE MONITORING AND SOCIAL COST-BENEFIT MODELLING

Based on real-life monitoring results for the 43 vessels and using consecutive models, several scenarios have been developed to assess the potential effects of the technologies on emissions reduction by the whole fleet, and subsequently on air quality in selected ports. First, the size and characteristics of the current fleet, such as engine inventory, were assessed. Second, a Baseline scenario was constructed which assumes business as usual until 2035, which means that part of the fleet will need to replace their old engine for reasons of aging and wear by a new one (mandatory Stage V). Third, the so-called CLINSH scenario was developed which in addition to the autonomous engine renewal in the Baseline, includes a maximum uptake of available (including demonstrated CLINSH-) technologies until 2035. The selection of options in the scenario is made according to social cost-benefit analysis. Both scenarios assume a modest adoption of zero-emission technologies.

Parallel to constructing the scenarios and based on the monitoring campaign fleet emissions were calculated and air quality modelling activities were performed. Via this approach it can be assessed that based on the different technique, ship category, ship size and engine load, a certain emission reduction potential for propulsion could be achieved *(see chapter 7)*. Next to reduction of emission from propulsion a separate analysis was conducted to estimate the additional benefit from OPS *(see chapter 8)*.

2.3 PRODUCTS

The CLINSH project has delivered the following tools and datasets that are available as open source for further research. These tools and datasets are available via the CLINSH website.

Table 1: Tools and datasets delivered by CLINSH.

1	Measurement protocols for measuring ship emissions on-board including engine parameters
2	Measurement protocols for exhaust plume measurements
3	Dataset of the measurement outputs
4	Emission factors methodology and results from application to real-life measurement data
5	Modelling tool for ship emissions (software)
6	IWT fleet development scenarios
7	IWT fleet emission scenarios
8	Novel application of air quality modelling and concentration mapping
9	Method for deriving NO_X emission factors from onshore measurements according to ship type, direction of travel and speed over the Lower Rhine
10	Datasets from intensive investigation of NO_X pollution at Rhine and large inland ports
11	Methodology for establishing emissions at berth and investigation of NO_X pollution in large inland ports
12	Energy Scan to evaluate energy management on board of barges and assess feasibility of Onshore Power Supply

3. Real-life measuring campaign

3.1 METHODOLOGY OF MEASURING AND DERIVING EMISSION FACTORS

Table 2: Overview of ships and technologies monitored in CLINSH

Technologies monitored	Engine class	# Ships monitored
Biodiesel (Hydrotreated Vegetable Oil)	"CCNR0"	1
Diesel	"	1
FWE (Fuel Water Emulsion)	"	2
GTL (Gas To Liquid)	"	4
SCR (Selective Catalytic Reduction)	"	2
SCR-DPF (-Diesel Particulate Filter	"	2
GTL+FWE	"	1
Diesel	CCNR1	3
FWE	"	1
GTL	"	1
SCR-DPF	"	4
Diesel	CCNR2	1
Diesel electric	"	4
Diesel electric + SCR-DPF	"	1
Diesel hydrogen injection	"	1
GTL	"	1
LNG	"	3
SCR	"	2
SCR-DPF	"	4
Diesel electric	Euro VI	1
Euro VI	"	2

CLINSH has monitored 43 vessels for their exhaust of nitrogen oxides (NOX) and particulate matter (PM) as well as fuel consumption during normal operation for several months *(table 2)*. The monitored fleet consisted of a large variety of vessels with different engines classified as "CCNR0" (which means unregulated), CCNR1 and CCNR2 (or the equivalent Stage IIA), that apply different exhaust abatement technologies such as SCR-DPF, diesel-electric or Fuel-Water-Emulsion (FWE) or use alternative fuels such as GTL or LNG. Battery-electric propulsion and hydrogen for either fuel cells or combustion engines was not part of the monitoring fleet as it was not mature at the time of vessel selection.

From the measurements results and literature, CLINSH has developed emission factor functions that relate specific emissions of NO_x and PM in g/kWh (propulsion energy at the propellor, engine out) to the engine loads (in percentage) for each ship in the CLINSH fleet. The methodology and results are presented in Annex 1. Table 3 shows the resulting emission factors and reductions relative to CCNR2.

Table 3: Emission factors derived from CLINSH measuring campaign [C] and literature [L]

	NO_x emission factor (g/kWh)	NO_x emission relative to CCNR2	PM emission factor (g/kWh)	PM emission relative to CCNR2
CCNR0 diesel	10.59 [C]	205%	0.406 [L]	308%
CCNR1 diesel	8.31 [C]	161%	0.132 [L]	100%
CCNR2 diesel	5.16 [C]	100%	0.132 [L]	100%
GTL	4.55 [C]	88%	0.091 [L]	69%
FWE	4.14 [C]	80%	0.066 [L]	50%
SCR-DPF CCNR1 A)	2.07 [C]	40%	0.132 [L]	10%
LNG	1.80 [L]	35%	0.013 [L] B)	10%
Stage V diesel	1.80 [L]	35%	0.013 [L] B)	10%
Euro VI diesel	0.40 [C]	8%	0.010 [L]	8%

A) Compared to CCNR1 the NO_x emissions are 25%, or a 75% reduction.

B) The emission limit for stage V is 0.015, the value of 0.013 is based on a 90% reduction as compared to CCNR2.

3.2 RESULTS AND RECOMMENDATIONS

Stage V and Euro VI are strict emission standards that diesel engines can only reach by applying after-treatment devices (SCR and DPF). One outcome of the measuring campaign is that the retrofitted after-treatment can come close to the Stage V limits. While several monitored ships demonstrate 70-80% NO_x reductions, others showed lower performance. One reason is that the installations were sometimes tuned to reach CCNR2 emission limits rather than the Stage V limits. Also, it seems more difficult for after-treatment installations to reach the Stage V NO_x limits. Among the other measured techniques only LNG monofuel reaches the Stage V limits, with a relatively high investment.

Stage V certified engines were not yet available to be included in the measuring campaign, except for Euro VI marinized engines certified as Stage V on two vessels. Unlike retrofitted SCR-DPF devices, Stage V and Euro VI engines are designed and certified as a complete package. As a result, the engine and after-treatment devices operate well together and emission reductions up to the emissions standards are expected in practice. This is confirmed by the performance of the two vessels whose marinized Euro VI engines reached the Stage V emission limits in the measuring campaign.

Policy recommendations

- CLINSH recommends stimulating, until zero emissions technologies are mature and supported by a regulatory and incentive framework, the a**ccelerated adoption of readily available NO_x and PM emissions reduction options.** A mix of technologies is needed most likely until 2035.
- CLINSH recommend real-life emission measuring of Stage V engines to confirm the expected low emissions performance in practice.
- The widespread adoption of Stage V (equivalent, including marinized Euro VI) engines and optimised after-treatment systems could be stimulated by applying the Stage V (equivalent) emission standard to the existing fleet in 2035. This should however not be a stand-alone measure but be combined with a Greening Fund, see further.
- The experiences in the CLINSH monitoring campaign show that basing vessel regulations on continuous real-life emission measurements rather than test-stand based emission standards needs further investigation, because the measuring campaign has revealed practical challenges. Similar to road vehicles, a periodic measurement of the exhaust gas values could be considered as part of mandatory vessel inspections.

Read more: CLINSH report on demo vessel installation and demonstration activities and CLINSH emission factors publication

4. Costs of emissions reduction

For the technologies monitored in the measuring campaign as well as several other emissions reduction options, CLINSH has performed a cost analysis along two lines: the total cost of ownership (TCO) of vessels with the various technologies, and the social costs and benefits of operating such vessels. This was done for a range of vessel categories, and within these categories also for low, medium and high fuel consumption vessels. The following graph shows the comparison for one vessel category.

The social costs and benefits were assessed using CLINSH monitoring results on emissions (NO_x and CO_2 emission factors) complemented with literature (PM emission factors) and using investment and operational costs based on monitoring the CLINSH vessels and literature (such as the Prominent [5] study). Costs included in the TCO analysis are investments, fuel costs (including urea), other operational costs, revision costs in the starting year and revision costs during the coming 15 years. Additional aspects in the social cost-benefit analysis are the environmental costs that arise from emitting CO_2, NO_x and PM (the so-called external costs that society incurs). These costs are calculated using a damage costs approach for NO_x and PM emissions, in which the effects (damage) of emissions on health, crop losses, material building damage and biodiversity loss are expressed in euros. The CO_2 price is based on the avoidance costs, which are the marginal costs of measures to reach the Climate targets in 2030 and 2050.

Figure 2 shows the results for one vessel category and one fuel consumption level. In order to show that results for a different vessel category and fuel consumption level can be very different, a similar graph is included in Annex 2. CLINSH has developed a digital tool that allows to view the results for all 18 vessel categories and low, medium and high fuel consumption, amounting to 54 variants.

Societal perspective

Figure 2 and table 4 show that battery electric vessels are optimal from the social cost perspective, but this is not a short-term commercial option because it is technologically immature, requires high (re)-investment and offers limited range. Hydrogen could remove the range restriction, but this technology likewise needs further development.

5 Project in the Horizon 2020 programme, 2015-2018

Figure 2: Example for one vessel category (110 m dry cargo vessel, medium fuel consumption) of Total Cost of Ownership of engine technology (investments plus variable costs) and social cost and benefit (sum of investment, variable costs and external costs), calculated as Net Present Value over 15 years (2020-2035).

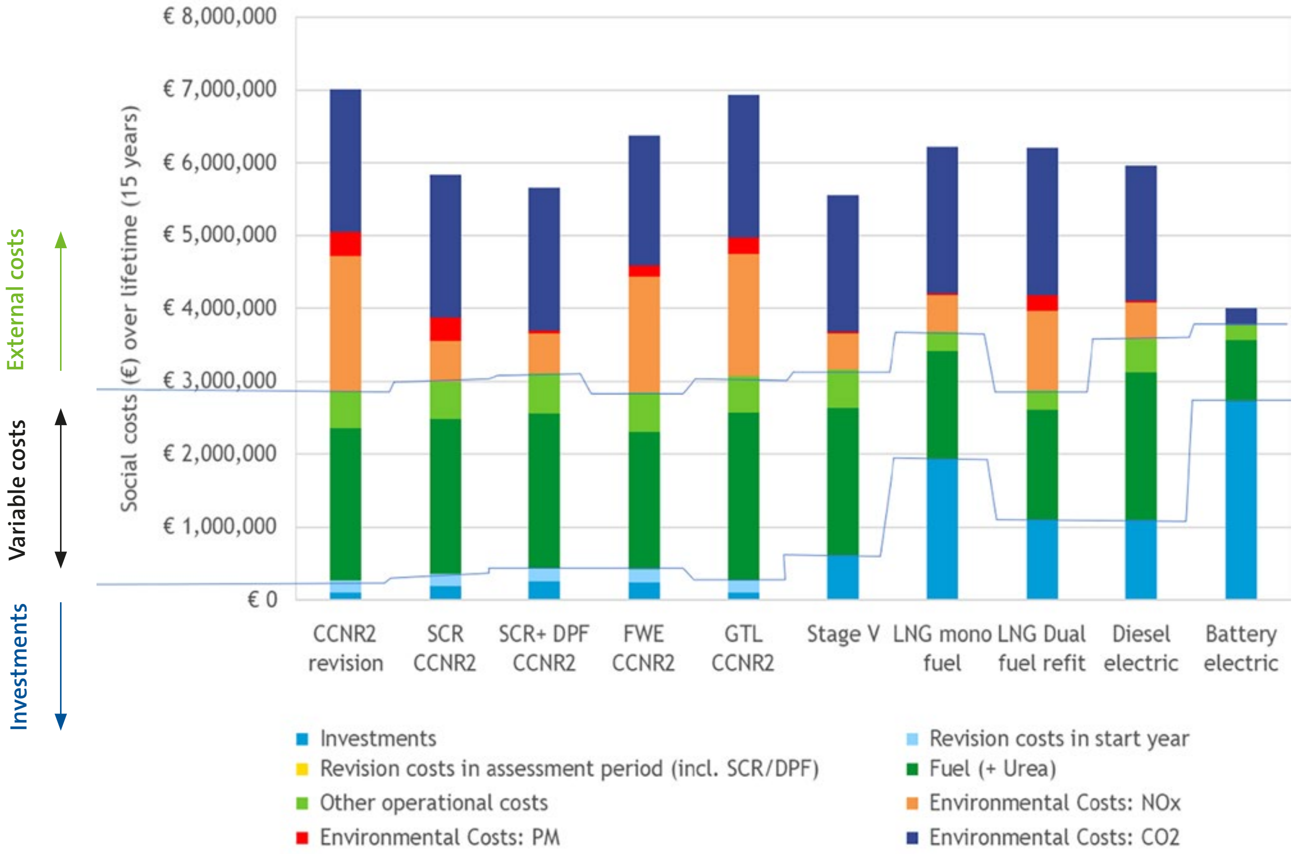


Table 4: Environmental costs of air polluting NO_X and PM emissions (million euro) over 15 years for one vessel category (110 m dry cargo vessel, medium fuel consumption). Amounts correspond to *Figure 4*.

	CCNR2 revision	Stage V	LNG mono fuel	LNG dual fuel refit	SCR CCNR2	SCR+ DPF CCNR2	Diesel electric	Battery electric	FWE CCNR2	GTL CCNR2
NO_X (M€)	1.86	0.49	0.49	1.08	0.56	0.56	0.49	-	1.58	1.67
PM (M€)	0.32	0.03	0.03	0.23	0.32	0.03	0.03	-	0.16	0.23

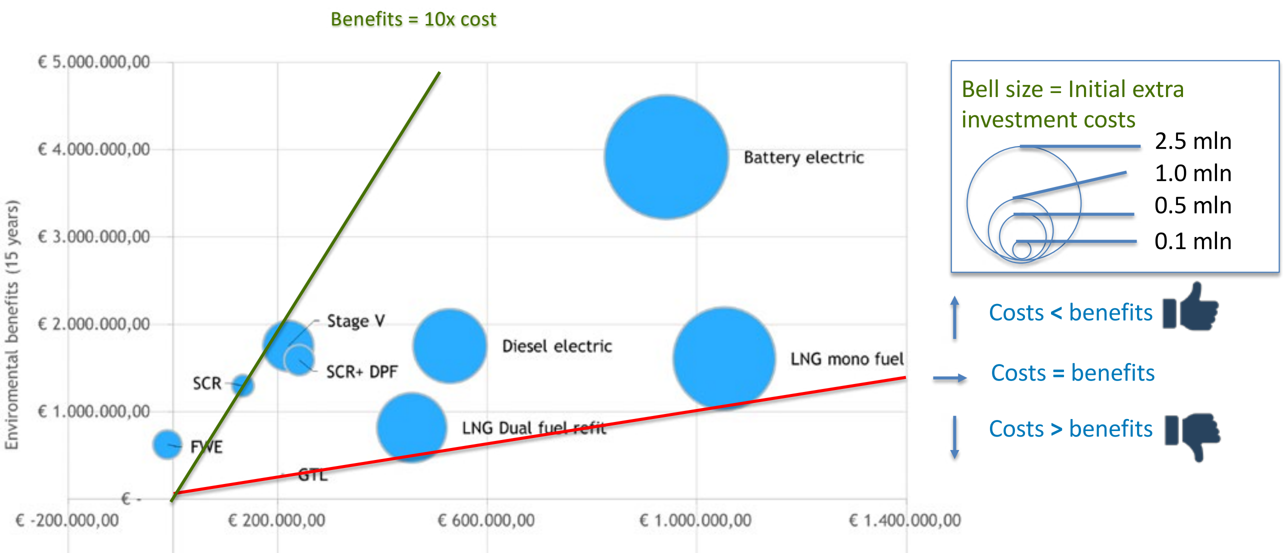
Next in line, and this is the same for most vessel categories, an expedited switch to Stage V or equivalent (Euro VI) engine renewal has the lowest social costs. SCR(+DPF) can be attractive under specific sailing profiles. For smaller ships than shown in the graph, GTL is often a suitable alternative, as for small ships the investment for engine renewal, retrofit after-treatment or FWE is relatively high and leads to higher socio-economic costs than for GTL. The analysis shows that revision, Dual-fuel LNG, diesel electric and FWE are less attractive from a social cost optimisation point of view in any vessel category.

Ship owner's perspective

However, from a TCO (total cost of ownership) perspective, revision of the existing engines (not an actual emission reduction measure) is the most attractive option for ship owners as it requires the lowest investments, but this brings little emission reductions and thus high external costs. SCR(+DPF), if well managed so that it functions adequately in practice, gives high reductions at relatively low investment, with similar cost/benefit ratio as Stage V but lower investment cost. SCR does increase the operational costs compared to revision because of the costs for urea. LNG (despite the very high investment) and FWE (because of reduced fuel consumption) are attractive for large fuel users in particular. Stage V engines do reduce fuel consumption, but this does not compensate the medium-high investment costs.

Figure 3 illustrates the tension between the two dimensions of total cost of ownership costs and social costs for a 110-meter cargo vessel. It should be noted that in the case of the 110-metre ship illustrated below, the social benefits are higher than the costs for *all* technologies.

Figure 3: Illustration of social cost perspective (here: environmental cost) versus total cost of ownership for ship owners in the case of a 110 meters dry cargo vessel. The costs are relative to revision of a CCNR2 engine. Options above the red line are beneficial from a societal point of view because the benefits are higher than the costs for the ship owners. The size of the bell indicates initial investment costs for the options.



This analysis was performed for all the vessel categories and sailing profiles and readers are kindly referred to the CLINSH socio-economic study (deliverable C1) if they want to learn more.

Policy recommendations

- The main recommendation from this analysis is that an integrated approach should be pursued in which the supporting policy is based on achieving the lowest social costs (including climate) rather than most cost-efficient technologies. The analysis shows that the preferable options from a societal point of view (lowest social cost) do not correspond with the preferred options from the cost perspective (lowest TCO) or cost-effectiveness perspective. For example, although FWE has the best cost-benefit ratio for a 110-meter ship with average fuel consumption (see figure 3), the total social costs will be lower when applying a Stage V engine, and in the future even more so with hydrogen or battery electric propulsion, with a profitable cost-benefit ratio.

- Stage V and SCR+DPF and to a lesser extent SCR demonstrate a very good cost/benefit ratio. Based on the modelling the Stage V engine is the best option in many cases, but closely followed by SCR-DPF. Fuel Water Emulsion shows the best cost/benefit ratio and will therefore be attractive to ship owners to invest in, but the environmental benefits per vessel are less than Stage V for instance. In practice the specific circumstances of the vessel, combined with policy incentives, will decide what is the best option.

- As the preferable options from a societal point of view do not correspond to the preferred option from the individual entrepreneur's perspective (TCO), the challenge lies in synchronizing the societal and individual interests. This amplifies the **need for policy intervention through investment support to ship owners** or by differentiated taxation of supporting the better options, in order to reduce the environmental costs from pollutants and to enable ship owners to opt for better solutions. CLINSH recommends creating incentives that promote the options with the highest emission reductions, even when they are more expensive, as the analysis shows that the additional social benefits of extra emission reduction outweigh the higher costs.

Read more: **CLINSH socio-economic study**

5. Fleet development scenarios

BASELINE SCENARIO AND CLINSH SCENARIO

CLINSH developed a reference fleet inventory for 2020 and two IWT fleet development scenarios towards 2035: one Baseline scenario based on "autonomous" engine renewal and one scenario with accelerated emission reduction, referred to as **the CLINSH scenario.** The assumptions for both scenarios are given in Annex 1. Both scenarios are built on the same assumptions regarding market developments of transport volumes (such as coal or oil products) and related developments in vessel and fleet size and include a modest uptake of Zero Emission technologies.

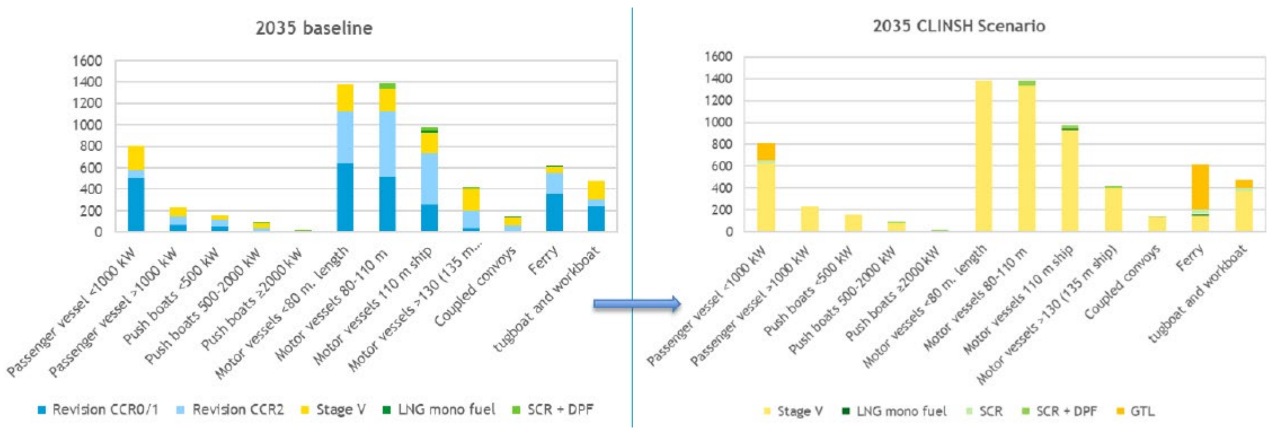
Autonomous engine renewal will decrease the NO_x and PM emissions of the IWT fleet. New engines introduced on the market are required to meet Stage V from 2019 and 2020 on, reducing emissions by over 90% when replacing stage IIIA, CCNRII or older engines. Stage IIA and CCNRII engines in stock, however, can still be sold until 2021/2022. As engines in IWT have such long lifetimes, emissions reduction by engine renewal alone will take a long time. The Baseline scenario assumes that only engine renewal with Stage V engines takes place according to a schedule defined by the age and average lifetime of the engines in place. About 24% of vessels is expected to re-motorise between 2020 and 2035.

Additional measures are needed to reduce emissions on the short term and to reach EU and national ambitions to reduce air polluting emissions. Emission reduction technologies and alternative fuels provide (retrofit) solutions for short-term emissions reductions. These technologies have been part of the pilot and monitoring campaign of CLINSH and the cost and benefits of these technologies were described in the previous chapter.

ACCELERATED IMPLEMENTATION OF AVAILABLE EMISSION REDUCTION SOLUTIONS

Up to at least 2035, emission reductions of NO_x and PM_{10} should therefore mainly come from other technologies than zero emission drivetrains. Autonomous engine renewal plays an important role but is not quick enough, because Stage V emission norms do not apply for current engines. In order to reduce emissions of the existing fleet in coming decades, accelerated implementation of technologies such as Stage V engine renewal, SCR-DPF, LNG and GTL is needed. The **CLINSH scenario** thus describes a pathway to accelerate the reduction of air pollutant emissions by Stage V engine renewal at scheduled revision moments and adoption of after-treatment technologies and alternative fuels when engine revisions are at least 10 years ahead, in the period before large-scale uptake of zero emission solutions occurs. The following graph shows the modelled engine inventory in 2035 in the Baseline and CLINSH scenarios.

Figure 4: Modelled engine inventory in 2035 in the Baseline and CLINSH scenarios.



It is assumed in the CLINSH scenario that for every vessel that is not scheduled for engine renewal before 2035, the ship owner will adopt the reduction option with the highest social benefit (except zero emission technologies), due to policy that will favour these options and will make it the most favourable from a total cost of ownership perspective, as shown in chapter 4.

It should be highlighted that this is a **model outcome,** based on only the best scoring technology of average sailing profiles and ship configurations, **assuming that policies are in place to overcome the financial barriers for the optimal options from the societal perspective. It is not a prediction,** but it illustrates the benefit of greening the fleet in the societally optimal way. For particular cases the model outcome could be different because the differences between the best and next-best scoring technologies can be small, and ship owners may make different choices and for instance invest in other technologies than modelled, based on their particular situation. Practical circumstances such as the timely availability of enough Stage V engines and after-treatment systems will also be important.

Zero-emissions technologies have on purpose been omitted from the scenarios. These technologies will play an important role in the long term, but their role is expected to be limited until 2035 because of range limitations end/or cost. CLINSH focuses on the application of air quality abatement technologies until zero-emissions technologies are mature and widely available.

The next chapter will discuss the emissions and air quality impact of the CLINSH scenario. The subsequent chapter discusses the financial impact of the CLINSH scenario and which policy is needed to make the CLINSH scenario a reality.

Read more: CLINSH report on fleet scenarios

6. Emissions and air quality

6.1 CURRENT AND FUTURE EMISSIONS IN THE MODEL REGIONS

As it is practically impossible to carry out emission measurements that cover the total fleet in the whole West-European region over a whole year, CLINSH developed an emissions model to calculate these emissions for the reference year and for the two fleet development scenarios. Focus was put on the regions surrounding the ports of Rotterdam, Antwerp, Duisburg and Nijmegen. The model combines the emission factors from the on-board measurements, AIS location tracking signals of all vessels sailing in the regions under study, and the fleet inventory and development scenarios to arrive at emissions per year in the model regions.

The following table shows the fleet emission modelling results. Whereas the Baseline scenario leads to NO_x and PM emission reductions in the order of 20%, the CLINSH scenario reduces these emissions in the order of 80%.

Table 5: Annual emissions from IWT in the model regions for the Baseline 2020/2035 and CLINSH 2035 scenario (kilotons).

	Rotterdam		Nijmegen		Antwerp		Duisburg	
In kilotons/year	**NO_x**	**PM_{10}**	**NO_x**	**PM_{10}**	**NO_x**	**PM_{10}**	**NO_x**	**PM_{10}**
Baseline 2020	2.68	0.098	1.32	0.041	0.97	0.034	2.05	0.063
Baseline 2035	2.06	0.074	0.97	0.028	0.75	0.027	1.59	0.046
	-23%	-23%	-27%	-32%	-23%	-22%	-22%	-2%
CLINSH 2035	0.72	0.032	0.28	0.004	0.27	0.013	0.45	0.010
	-73%	-65%	-79%	-89%	-72%	-61%	-78%	-84%

6.2 CURRENT AND FUTURE AIR QUALITY IMPACT

CLINSH developed a method to identify the inland shipping contribution to urban air quality for different emission scenarios in the cities of Antwerp, Rotterdam, Nijmegen and the greater Duisburg area. It involves a consistent approach to derive land-based and shipping emissions to be applied in different air quality models. The approach is replicable in regions throughout Europe. The methodology and results are presented in Annex 3.

For the Rotterdam area the results show that in the Baseline scenario in 2020, inland shipping contributes between 0.2 to 3 µg/m^3 with an average of 1.2 µg/m^3 to NO_x concentrations. In the Baseline scenario in 2035, the contribution from IWT in the Rotterdam region varies between 0.2 and 2.6 µg/m^3 with an average of 1.0 µg/m^3. The contribution of the shipping

Table 6 : NO_x reduction potential of the CLINSH scenario in Rotterdam region.

Scenario	Max. contribution µg/m^3	Average contribution µg/m^3	Reduction vs. average Baseline 2020
Baseline 2020	3.0	1.2	-
Baseline 2035	2.6	1.0	16%
CLINSH 2035	1.3	0.4	66%

is only slightly lower than in 2020. The CLINSH scenario has a significant effect on air quality however: the contribution from IWT to the NO_x concentrations in Rotterdam varies between 0.1 and 1.3 µg/m^3 with an average of 0.4 µg/m^3. Table 6 summarizes the results. Similar results have been calculated for Antwerp, Nijmegen and greater Duisburg areas.

The EU Air Quality Directive sets mandatory annual average limits for nitrous dioxide (NO_2) and PM. The value to be complied with for NO_2 is an annual average of 40 µg/m^3. The CLINSH studies show that emissions from inland vessels cause part of this pollution in the cities along the major waterways. However, IWT is not the main cause of the high levels of pollution in residential areas. Therefore, exhaust gas reduction measures on inland vessels can only be one part of the necessary, much more comprehensive package of measures.

6.3 AIR QUALITY MEASUREMENTS

In addition to modelling for the four regions, the contribution of inland vessels to air quality has also been measured in North Rhine-Westphalia. The measuring programmes in the ports of Neuss/Düsseldorf and Duisburg as well as the measuring points on the Rhine have shown that the pollution of the ambient air with NO_x and PM_{10} caused by the emissions of inland navigation is not as extensive as assumed at the beginning of the project. The annual average increase in pollution caused by about 110,000 passing inland waterway vessels at the German-Dutch border near Bimmen/Lobith directly on the shore is in the range of 1-2 (left bank, windward) to 5 µg/m^3 (right bank, leeward) for NO_2. This is in the same range as the modelling results for Rotterdam presented before.

The modelling for the air pollution cause analysis at the CLINSH monitoring sites on the Rhine in Duisburg and Neuss conform to the real measured data. The results show that the effect of additional pollution from vessels decreases very quickly with increasing distance from the shore. For the areal pollution in the large cities along the Rhine at a greater distance from the river, emissions from local road traffic on the main roads are the dominant source.

Read more: CLINSH report on fleet scenarios,
CLINSH air quality concentration maps,
CLINSH Harbour monitoring reports North Rhine-Westphalia Part A

7. Realising the CLINSH scenario

7.1 COSTS FOR THE SCENARIOS

The table shows the modelling results for the two fleet development scenarios. The number of vessels involved is that of the West-European fleet minus the vessels that need to "autonomously" renew their engine, considering the age of the engines, and also excluding vessels already using LNG, SCR(+DPF) and Stage V.

Both scenarios include investment costs for autonomous engine renewal (€650 million for Stage V engines). Additional "investment" costs in the Baseline scenario are the costs for revision. The modelling results show that investing another **€1.27 billion in the CLINSH scenario** (on top of the investments in the Baseline scenario) yields a social benefit of several factors higher **(€4,9 billion)**, especially because of reduced social costs of the effects of NO_X emissions. Investment subsidies of usually 40-60% of the price difference between a cleaner technology and the established practice would close the €0.76 billion TCO gap between both scenarios. However, even 60% of the price difference may be too low for many capital-starved vessel owners to make such investments.

Table 7: NO_X reduction potential of the CLINSH scenario in Rotterdam region.

Total social costs	Baseline scenario in 2020 - 2035	CLINSH scenario in 2020 - 2035	Difference
Number of vessels involved, Western-Europe A)	6,572	6,572	
Social costs with 15 years lifetime (M€), consisting of:	26,139	21,280	-4,859
• TCO with 15 years lifetime (M€)	10,751	11,512	761
• CO_2 costs with 15 years lifetime (M€)	8,074	7,867	-207
• NO_X costs with 15 years lifetime (M€)	6,051	1,788	-4,263
• PM costs with 15 years lifetime (M€)	1,264	112	-1,151
Initial investment costs (M€)	1,123	2,393	1,270
Diesel consumed over 15 years (mio litres)	14,662	14,286	-376
TCO increase per litre of diesel (€ per litre)	0.733	0.806	0.053 B)

A) Excluding vessels already using LNG, SCR(+DPF), diesel-electric

B) TCO (Total cost of ownership) gap divided by diesel consumed in Baseline and CLINSH scenario

The minimum tax on IWT diesel proposed in the Energy Tax Directive is €0.9/GJ or 3.24 €cts/litre, whereas if we divide the TCO gap by the diesel consumption in IWT we come to a TCO increase of about 5.3 €cts per litre. This means that if the revenue from IWT fuel could be allocated for the greening of IWT and depending on the tax level that is decided on, this could nearly close the TCO gap. It should be noted that the size of the TCO gap differs for various vessel categories.

If the total IWT fleet, hypothetically, switches over to 100% biofuels such as Hydrotreated Vegetable Oil in order to meet Climate goals, the TCO would be raised with about 15 €cts per litre, amounting to €2.1 billion in the CLINSH scenario and €2.2 billion in the Baseline scenario (the difference caused by the better fuel efficiency in the CLINSH scenario). Assuming 90% CO_2 reduction relative to diesel, it would however also raise the social benefits of CO_2 reduction by about €7 billion giving net social benefits of 5 billion euro's taking into account the investment costs. It should be noted however that 90% CO_2 reduction will be achieved only if all of the HVO is coming from waste-based feedstock, but a substantial amount of HVO on the market is currently not from waste-based feedstock.

Read more: CLINSH socio-economic study

7.2 POLICY RECOMMENDATIONS TO ACHIEVE THE CLINSH SCENARIO

- The socio-economic analysis shows that Stage V (including Euro VI) engine renewal is **optimal from a societal perspective** for many ship types. The moment of engine revision would be best in terms of cost/benefit to stimulate accelerated Stage V engine renewal. The relatively high investment costs for Stage V engines are partly compensated by improved fuel efficiency and low emissions as demonstrated for the Euro VI engines in the monitoring fleet. SCR-DPF (with lower investment costs than engine renewal) and GTL (especially for smaller vessel types with lower fuel consumption) also score well. **An incentive scheme should make at least Stage V, SCR-DPF, FWE and GTL attractive for the entrepreneurs to invest in.**

- The EU and Member States should provide incentives for this accelerated adoption through an **IWT Greening Fund or grant schemes.** The fund should be open to both emission reducing and zero emissions technologies until 2035; thereafter the fund could be for zero emissions technologies only once the Stage V (equivalent) mandate enters into effect for all vessels.

- Ship owners who use clean technologies or fuels could receive a reduction or exemption on the existing waste disposal charges.

- Budget for the fund or grant schemes could be raised by **allocating revenue from the taxation** of IWT fuels that is proposed in the Energy Tax Directive. A levy on the fuel, similar to the CDNI [6] regulated waste disposal charge paid by vessel operators when bunkering, but differentiated to the emissions performance of the vessel, could also be considered.

- The monitoring demonstrates that it is possible to reach the Stage V emission limits with retrofit after-treatment technologies and alternative fuels under real-life sailing conditions, however this requires optimal management of the systems. The performance of after-treatment technologies should **therefore be monitored** to make sure it is functioning well **in practice**. The assignment and funding of the monitoring should be arranged by the policy makers.

- The widespread adoption of Stage V (equivalent, including marinized Euro VI) engines and optimised after-treatment systems could be stimulated by applying the **Stage V (equivalent) emission standard to the *existing* fleet in 2035**. This can only be achieved when the proposed Greening Fund is in place. It would also increase the effectiveness of such Fund because ship owners will have an additional rationale to re-motorise before 2035, while not precluding the adoption of ZE technologies when these become widely available from 2030 onwards.

- Given the scarce capital availability in the IWT sector it is commendable to seek permission to **provide investment support up to 80%** over the price difference notwithstanding EU State aid laws; also for Stage V engine renewal, even though this is the ruling emission standard for new engines. If subsidizing Stage V (including Euro VI) engines is not allowed, then support could be funnelled via grants for replacement and scrappage of old engines. The level of support (percentage applied) could be differentiated according to the emission reductions potential of the technologies.

- In order to reduce CO_2 emission reductions along with NO_x and PM emissions, CLINSH also endorses the development of **policies for accelerated uptake of biofuels and (sustainable hydrogen based) e-fuels in** IWT fleets. Such uptake is in line with the CCNR Zero emission Transition study's Conservative pathway, which involves mainly the biofuel Hydrotreated Vegetable oil (HVO) for diesel engines and liquid biomethane (bio-LNG) for LNG engines. Also, HVO/GTL blends or in future e-fuels/GTL blends may be attractive for shipowners, as those blends would make the price difference to diesel smaller than with 100% HVO or e-fuels.

6 Convention on the collection, deposit and reception of waste produced during navigation on the Rhine and inland waterways (CDNI).

- CLINSH also endorses **policy for promoting Zero Emissions technology:** more research on application of ZE technology (battery electric, hydrogen); funding for pilots/demonstrations towards creating a Zero emissions IWT corridor with battery swap stations and fuel stations for flow cells and fuel cells; and investments in making batteries, flow cells, fuel cells and hydrogen cheaper. A target of zero-emissions IWT in 2050 is ambitious considering that the technology is not yet mature. Zero emissions technology can be a mainstream option after 2035 and should be stimulated once market-ready. However, in order to achieve short-term air pollutant emissions reductions, Stage V engine renewal and retrofit of after-treatment technologies merit support in the meantime.

- Hybrid-electric, entailing a diesel or gas engine providing power for an electrified driveline, is an interesting option to **prepare for Zero Emission.** Hybrid can for some ship categories be the next best option from social cost perspective, and a benefit for the ship owner is that the electric driveline has residual value when the combustion engine will be replaced in future by batteries or fuel cells. The development and implementation of cheaper and better generator sets for hybrid drive should also be supported by the aforementioned IWT Greening Fund.

- **Local regulations** can help make the transition via lower emission technologies towards Zero Emissions. Aligned with financial support for engine renewal until 2035 (Greening Fund) and ahead of the proposed Stage V (equivalent) emission standard for the existing fleet in 2035 could be the implementation of **low emission zones in ports.** This could be succeeded by ZE zones in ports in 2050 for instance. CLINSH recommends investigating the feasibility and impact of such zoning. More widespread adoption of differentiation of port dues (exempt for ZE, medium for Stage V, highest for CCNR 0-1-2 until phased out), harmonized across the Rhine states, would provide another incentive for greening the fleet and would level the playing field for owners who already invested in greening technologies.

- **Emission labelling** may be used as the basis for local regulation of IWT vessels. Using input from the CLINSH consortium, the Netherlands have developed an emission labelling method that rates both air pollutant and climate emissions. This so-called *Binnenvaart Emissielabel* (IWT emission label), launched on 15 November 2021, could be used for differentiating port dues and for environmental zoning. The aim is to have the labelling method applied across Europe.

Read more: **CLINSH report on financing mechanisms**

8. Onshore power supply

8.1 RELEVANCE OF POLICY SUPPORTING ONSHORE POWER SUPPLY

Besides emissions from ships sailing, emissions from vessels at berth are also of interest. Emissions at berth can be reduced by electrification of ships, but this will take time. Other solutions are OPS and/or batteries for vessels' hotel functions at berth, where batteries can be charged using OPS, an onboard generator and/or solar panels. As the Baseline and CLINSH scenarios foresee some electrification and hybridisation but mostly adoption of exhaust after-treatment and cleaner fuels, there will be a need for OPS for the coming decades.

CLINSH developed a methodology to assess the emissions of vessels at berth, which uses AIS location tracking data for estimating the numbers of port calls and specific auxiliary engine emission factors for installed generators in the IWT fleet. [7] The analysis was done for some individual ports but is replicable for every port in the EU. The results show that the contribution of emissions at berth to total IWT emissions in ports varies but does not exceed a few percent. However, these emissions often take place at berths situated near highly populated areas where many people are exposed to these emissions as well as noise. Social cost-benefit analysis shows that the investment costs of OPS installations are more or less equal to the societal benefit. This justifies public policy support for OPS.

Particularly high emissions are caused by tankers unloading with on-board pumps and by cruise ships and hotel ships. Therefore, the berths of tankers at the tank farms and the berths of river cruise ships and hotel ships close to cities should be equipped with OPS systems as a matter of priority.

As part of CLINSH, an Energy Scan Campaign was held in Flanders . The energy scan campaign is a best practice example of policy support for OPS. The main results of the campaign are:

- Increased awareness of 26 skippers about the energy management on board their barge. They were advised about the main energy saving measures that would even result in a return on investment in a few years' time, such as minimizing the use of electric heating, installing LED lighting and optimizing the use of OPS.
- The vessels were evaluated as to whether their power network on board is compatible with the onshore power box. The campaign found that technical limitations for the use of shore power are limited. 50% of the participating skippers already use OPS without any problems.
- The energy scan campaign revealed that onshore power supply is in some cases a financially attractive solution compared to the use of a generator.

7 It should be noted that the use of AIS signals to determine the number of ships in port must be further developed in order to determine realistic ship numbers. A comparison with the data of the port operators is necessary.

8.2 RECOMMENDATIONS FOR A COHERENT OPS STRATEGY

The studies in CLINSH about OPS focussed on port characterization (where is OPS best deployed), available technologies and solutions, Standards & Regulations and promotional campaigns to increase utilisation of OPS. CLINSH also supported demonstrations of innovative OPS solutions. The resulting deliverable is the OPS best practice guide.

The following policy recommendations for a coherent OPS strategy have been developed from three perspectives namely (A) location characteristics, (B) economic rationale and (C) technical and operational considerations.

A. Locations to invest in OPS

- Invest in OPS where air quality and/or noise concerns are most pressing and where the cost effectiveness of euros spent to reduce emissions is highest. The top-3 type of locations are river cruise berths, waiting docks and overnight mooring, and tanker berths. Sometimes container terminals, home ports for nautical services and maintenance and repair yards are promising as well.

B. Economic rationale to use OPS

- **Price setting:** the business case for a ship owner for using OPS should be at last cost-neutral to using the on-board generator. The introduction of an EU-wide permanent tax exemption for OPS in accordance with Article 15 of the proposal for a reviewed Energy Taxation Directive (COM) (2021563 final) would encourage the deployment and use of OPS based on the strict requirements in AFIR and FuelEU Maritime. Such an exemption would also level the playing field in the maritime sector as the fuel used for onboard generators is today also untaxed.
- The price of OPS is strongly determined by the investment cost in the cabinets and grid connections. CLINSH recommends maintaining and expanding **funding mechanisms for OPS** such as CEF2, in line with Naiades III, Policy package Fitfor55, European Parliament "resolution Nachtegaal" 2021, to realise OPS in Core and Comprehensive ports and possibly other funding for other ports including recreational ports. [8] It is important to develop strategies so that current and planned OPS infrastructure in ports could become a stepping-stone for future expanded power infrastructure needed to achieve the Zero Emission ambition for 2050.

8 The proposed AFIR targets for OPS should be reconsidered, as they require "at least one installation" providing shore power to inland vessels in Core (2025) and Comprehensive (2030) ports, but one installation only serves one vessel at the time.

- The potential for additional local **regulation** to mitigate berth-emissions could be investigated further. A policy option that emerged from the scenario work is to impose an emission standard or age limit for on-board generators used in ports to remove the oldest, most polluting ones and in case of river cruise vessels also to mandate the use of OPS when berthing with passengers. CLINSH estimated the potential emission reductions at berth for these combined measures to be up to over 95% for PM and up to more than 85% NO_x reductions. Further investigation is needed to determine how such a measure can effectively be enforced.

C. Technical / operational standardisation for level playing field

- The **type of connectors** used for OPS is generally standard in each country but is not standardised internationally. Standardisation of connectors, at least on connected waterways, would allow ships that sail across national boundaries to use OPS in any ports where it is available. Better cooperation between ports and policymakers in different countries and EC needed for the harmonisation of the connectors.
- **Payment systems** should be made convenient for the skippers. Harmonisation of management and payment systems across Europe is assumed to increase the uptake of OPS. This could include linking the booking of a berth and OPS with payment for port dues, freshwater and waste Linked in with the booking system could be asking for information such as OPS cable length available on the ship allowing the port to optimise the allocation of berths to maximise the availability of OPS connection points for ships wishing to use them.
- **Communication and creation of awareness** of the business case with ship owners and operators is needed. As part of CLINSH, Flanders have run a programme of energy scans which, besides unveiling specific insights for improvements, also helps to involve ship owners and make them aware the actual costs of using the generator compared to OPS.

Read more: **CLINSH report on emissions at berth** and
CLINSH Onshore Power Supply best practice guide
CLINSH Harbour monitoring reports North Rhine-Westphalia Part B

9. After-LIFE

- CLINSH has delivered the first accurate estimate of IWT emissions and reduction opportunities. To date, all the ships in the CLINSH fleet generate data on their real-life emission performance. After the formal end of the CLINSH project, m**onitoring will continue** for five more years. This will generate a large set of data that can be used by scientists, modelling experts and students.

- The results of the project (database, scenarios, air quality maps) will be **available as open data,** accessible on request. Besides the results, the CLINSH website will stay available and actual for at least five years after the project ends.

- CLINSH has produced or enriched several datasets that can be used for future policy support and tooling. For example, EICB will use the CLINSH monitoring outcome to update the **IWT Greening tool** in 2022, when the Energy Tax Directive implications for business cases and TCO have become clear. The development of SCAB by CLINSH will generate input for their update as well.

- CLINSH clearly points out that there is a discrepancy between the societal perspective and the skipper's perspective on what would be the best greening options. The challenge lies in synchronizing the societal and individual interests. The CLINSH partners will investigate and promote that the **Social Climate Fund** proposed in the Fitfor55 package will include a facility to support skippers, being both households and small businesses with limited access to capital, in their investment in greening their vessels.

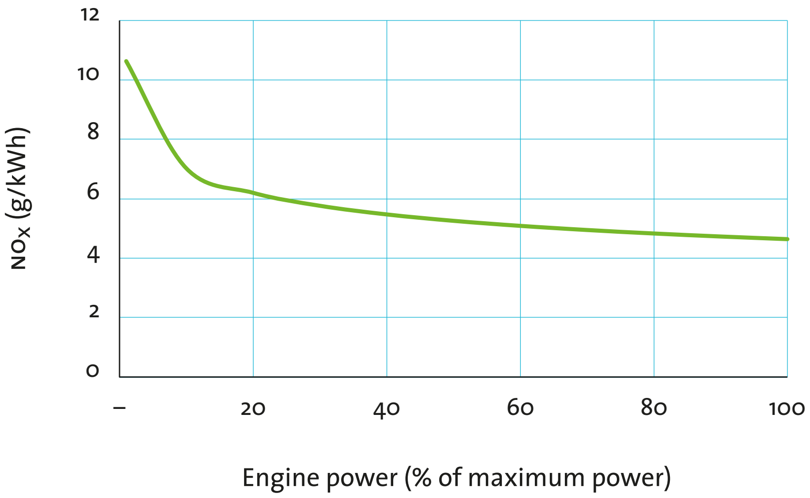
- To promote best practices and stimulate the expedited Stage V transition, CLINSH partners propose that a **permanent structural platform or European knowledge centre** be set up by the European Barge Union (EBU). An example of such a 'Center of Excellence' is the InnovationLab in the Netherlands. The CLINSH partners will contribute actively to and lobby for the creation of such a knowledge centre.

Read more: CLINSH After-LIFE plan

Annex 1: Emission factors

CLINSH has developed emission factor functions that relate specific emissions of NO_x and PM in g/kWh to the engine loads in % for each ship in the CLINSH fleet. Next, averaged emission factor functions were created for ships belonging to the CCNR classes and abatement technologies. Implausible data have been sorted out. The resulting functions are power functions of the form $m \cdot (\%EngineLoad)^n$, determined by two parameters m and n. Figure A1 shows an example of the NO_x emission factor function for a measured CCNR2 engine. Further details about this approach can be found in the CLINSH report on current and future emissions. The continuous NO_x measurements were used to create emission factors as follows.

Figure A1: Example of a NO_x emission factor function for a CCNR2 engine.



NO_x emission factors

As the amount and quality of the data for deriving emission factors differed depending on the engine type and abatement technology, CLINSH applied different approaches for different engines:

- For the non-refitted engines, the function coefficients for “CCNR0”, CCNR1 and CCNR2 engines are used.
- For the abatement technologies, CLINSH uses function coefficients that reflect the percentage reduction seen in the comparison of before-after refit pairs. While the parameter n, that shapes the curve, is taken from the on-board measurements, m is adapted to conform to the reduction rate.
- The monitoring programme included two marinized (adapted from truck applications to vessels) Euro VI engines, certified as Stage V engines, but no other Stage V engines.

Therefore, CLINSH uses the limit values in the EU Stage V emission standard. For LNG also, the reduction percentages according to literature are used. Here, adopting the function coefficients m and n to E3 cycle means found in literature, we use the coefficient n for CCNR2 engines and adapt the parameter m so that the average emissions conform to the E3 cycle mean found in literature.

PM emission factors

It was planned to use the non-continuous onboard PM measurements to derive emission factors for PM, but the emissions measured during campaigns turned out to be about a factor 2 lower than expected from results found in literature. The reason was the sampling method used. Therefore, CLINSH decided not to use the measured emission factors for emission modelling, but to use literature values of E3 cycle averages instead. To get the function coefficients needed in the model, CLINSH did use the shape of the curve found from the measurements and adopted the intersect so that the demanded E3 value for the respective technology was met. As no measurements could be used, it was not possible either to estimate the error of the resulting emission factors.

Table A1: Emission factor function coefficients for NO_X, resulting E3 cycle average and estimated error.

Engine type	m	n	E3 average	Error
CCNR0 diesel	26.8	-0.23	10.59	3.66
CCNR1 diesel	25.28	-0.27	8.31	3.66
CCNR2 diesel	10.63	-0.18	5.16	1.65
CCNR1 SCR-DPF A)	10.28	-0.39	2.07	1.65
CCNR2 GTL	9.55	-0.18	4.55	1.70
CCNR2 FWE	21.45	-0.40	4.14	2.58
LNG	3.8	-0.18	1.8	1.25
Stage V diesel	3.8	-018	1.8	–
Euro VI diesel	0.85	-0.18	0.40	0.29

A) Compared to CCNR1 the NO_X emissions are 25%, or a 75% reduction.

Table A2: PM emission factor function coefficients used and the E3 cycle average.

Engine type	m	n	E3 average
CCNR0 diesel	1.05	-0.23	0.406
CCNR1 diesel	0.34	-0.23	0.132
CCNR2 diesel	0.34	-0.23	0.132
CCNR2 GTL	0.04	-0.27	0.091
CCNR2 FWE	0.04	-0.27	0.066
CCNR1 SCR-DPF	0.21	-0.20	0.013
LNG	0.17	-0.23	0.013 [L] A)
Stage V diesel	0.03	-0.27	0.013 [L] A)
Euro VI diesel	0.04	-0.27	0.010

A) The emission limit for Stage V is 0.015, the value of 0.013 is based on a 90% reduction as compared to CCNR2.[9]

CO_2 emissions

CO_2 emissions by the CLINSH vessels were not measured but it is possible to estimate CO_2 emissions from the fuel consumption. Instead of measuring the engine loads in kW the engine loads were calculated from the fuel consumption using a fixed conversion factor. For this reason, it was not possible to develop generalized fuel consumption functions that relate fuel consumption to the engine loads, and hence, it was not possible to calculate annual total CO_2 emissions for the total fleet like done for NO_x and PM emissions.

9 Prominent-iwt.eu

DEVELOPMENT OF ONSHORE EMISSION FACTORS

The additional use of two automatic measuring stations for the CLINSH measuring programmes in North Rhine-Westphalia made it possible to measure the concentrations of NO_x at intervals of 5 seconds. When evaluating the measurement signals, it was possible to record the pollution peaks of passing ships in suitable wind directions, to assign them to individual ships by means of the AIS signals and to quantify them. Such an evaluation was successful for about 18,000 ships; Measurements at the station in Duisburg will continue in 2022.

With these evaluations, it was possible to derive emission factors for the passing ships from the onshore measurements and to classify them with regard to direction of travel (upstream/downstream), speed and ship size. These classified data form an important basis for developing a new method for more realistic recording of the emissions actually caused by moving inland vessels on the basis of real emission measurements and the associated speeds (over ground).

This provides a strong basis for the upcoming update of the North Rhine-Westphalia "Inland Vessels" emission register. In combination with the method for a more realistic determination of the emissions of ships at berth, also developed within CLINSH, there are now new possibilities to better quantify the emissions of inland vessels in the future.

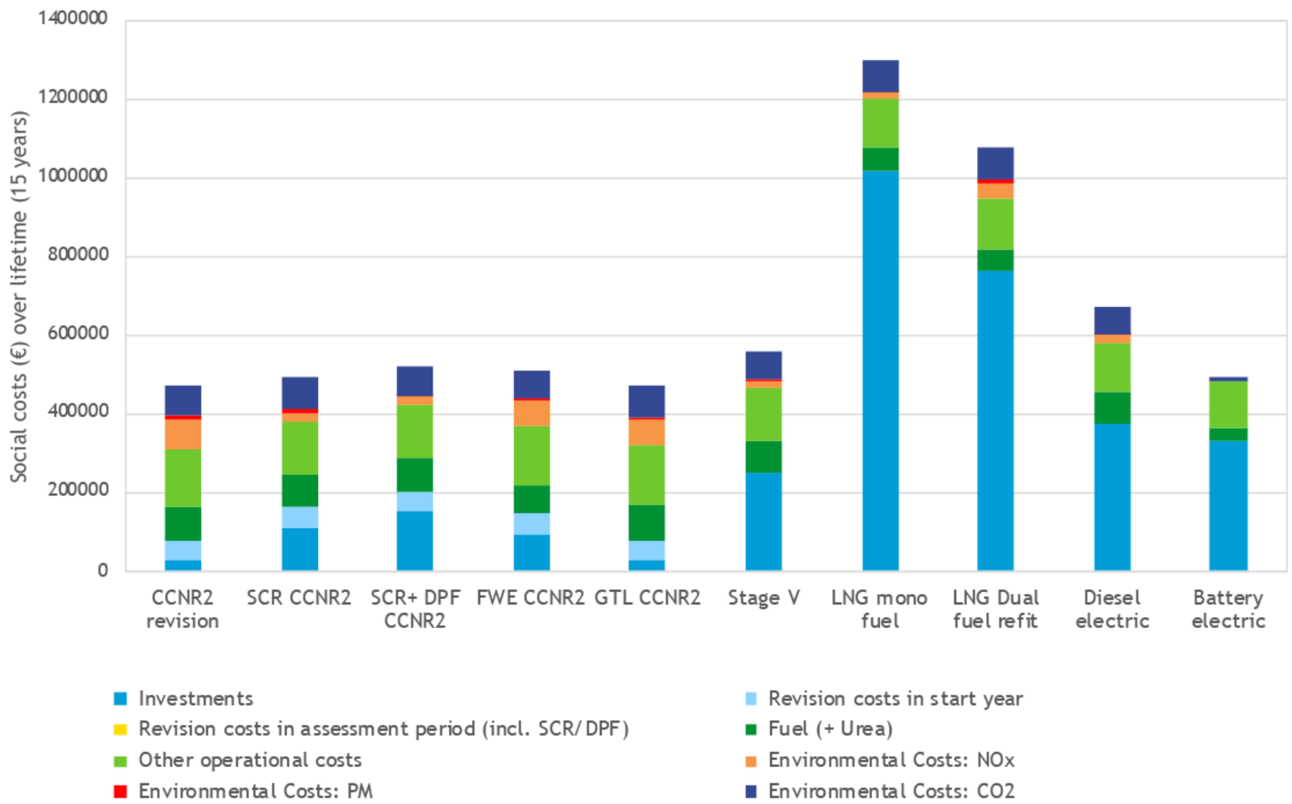
The CLINSH project has thus helped to improve the future determination of inland vessel emissions. This method will be applied in the future for the Lower Rhine in NRW and can also be transferred to other river basins in a modified form. It provides a better basis for any necessary action planning for the implementation of the EU Air Quality Directive.

Annex 2: Society incurred costs

Chapter 4 presents the cost analysis for different technologies and vessel categories. Costs included in the TCO analysis are investments, fuel costs (including urea), other operational costs, revision costs in the starting year and revision costs during the coming 15 years. Additional aspects in the social cost-benefit analysis are the environmental costs that arise from emitting CO_2, NO_x and PM (the so-called external costs that society incurs). Figure 2 showed the results for one vessel category and one fuel consumption level. Figure A2 in this Annex presents the results for a second combination of vessel category and fuel consumption level in order to show that results differ.

CLINSH has developed a digital tool that allows to view the results for all 18 vessel categories and low, medium and high fuel consumption, amounting to 54 variants.

Figure A2: Example for Passenger vessel 250 - 500 kW, low fuel consumption, of total cost of ownership of engine technology (investments plus variable costs) and social cost and benefit (sum of investment, variable costs and external costs), calculated as Net Present Value over 15 years (2020-2035).



Annex 3: Fleet scenarios

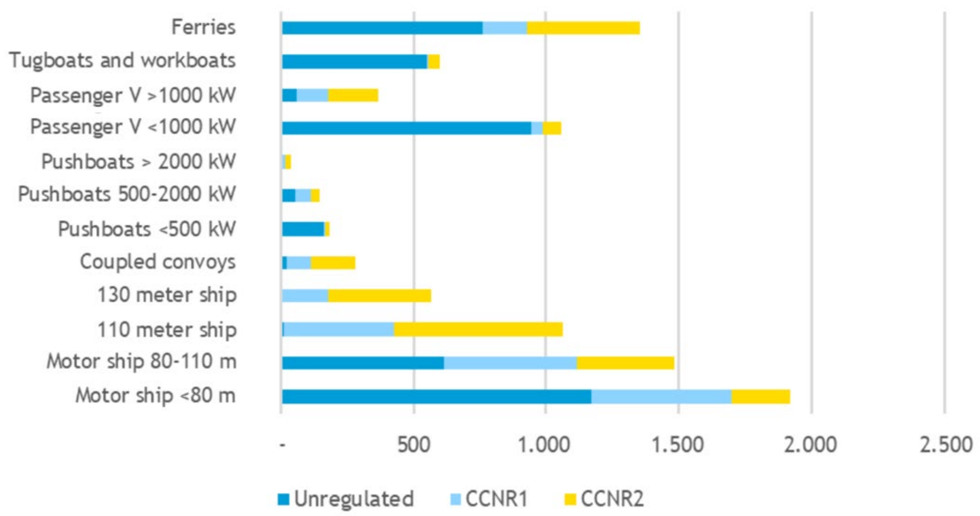
REFERENCE FLEET INVENTORY 2020

The following figure shows today's composition of the fleet, differentiating between vessel categories and engine types (unregulated, or regulated according to CCNR1 or 2 emission standards).

The two scenarios that have been investigated in CLINSH are a Baseline scenario and the so called CLINSH scenario. The scenarios are described for the period 2020 to 2035 with measures taken in the period 2022-2035. From 2022, all new engines installed need to meet the Stage V emission requirements at least.

Figure A3: West-European IWT fleet inventory (2020)

Data for base year (Prominent / STC Nestra)



ASSUMPTIONS FOR THE BASELINE SCENARIO 2035

In the Baseline scenario, it is assumed that engine renewal leads to the introduction of new Stage V diesel engines. It is assumed that no other emission reduction technologies will be installed in the baseline scenario, as there are insufficient financial incentives to do so. Not taken into account in the Baseline are any effects from ambitions set in the Mannheim declaration (35% reduction of pollutants and GHG emissions in 2035), the Dutch climate agreement (150 electric drivetrains in 2030, 35-50% reduction of air polluting emissions in 2035), EU Green Deal or any other policy ambition, as policies and regulations to reach these ambitions are still in development and it thus remains uncertain how and if these targets will be reached.

ASSUMPTIONS FOR THE CLINSH SCENARIO 2035

In the CLINSH scenario, autonomous engine renewal will lead to same amount of Stage V engines entering the fleet as in the Baseline scenario, but part of them will now not be diesel engines. The CLINSH scenario focuses on applying NO_x and PM_{10} reducing measures up to 2035 to the part of the fleet that will not renew their engines autonomously between 2020 and 2035.

It is assumed that in 2035 on these ships the NO_x and PM_{10} reduction measures will have been implemented with the lowest societal costs measured over a period of 15 years. Given the uncertainties of future emission regulations an engine lifetime of 15 years is assumed, although actual lifetimes of engines and reduction techniques can be longer. Revision of the current engine or early placement of a Stage V engine can be outcomes as well, when one of these options results in the lowest social costs. For each vessel category the best option is chosen, differentiated between low, medium and high fuel consumption.

The measures are taken during engine revision, assuming that engine revision will take place for all ships during this period. Ships with a zero-emission driveline are considered an option as well, but with a maximum of 150 in 2030 according to the ambition set in the Dutch Green deal, and 300 in 2035. Measures that only reduce CO_2, like biofuels, are not considered in the CLINSH scenarios as such, as they do not have a significant (positive or negative) effect on pollutant emissions as compared to their fossil fuel counterparts.

ZERO EMISSION OPTIONS

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, and the Mannheim declaration, CO_2 reduction in IWT has become an important goal as well. Options such as battery-electric engines, hydrogen-fuelled engines (either fuel cells or combustions engines) and biofuels are getting more and more attention. Biofuels, however, do not have a significant impact on emission reduction of air pollutants and should therefore be combined with other emission reducing technologies.

Battery-electric and hydrogen-fuelled vessels on the other hand have no combustion emissions at all, or much lower emission in the case of hydrogen in combustion engines. Very few zero emission options, however, are market ready for IWT. The Dutch Climate agreement (and accompanying Green Deal) sets the 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. Up to 2035, therefore, zero emission vessels are expected to play a limited yet growing role, used for specific short and medium-distance trips.

Therefore, ZE technologies have on purpose been omitted from the scenarios, but we do expect these technologies to play an important role in the long term.

FLEET COMPOSITION IN THE CLINSH SCENARIO

The following tables A3 and A4 show the resulting fleet composition in the Baseline scenario (2020 and 2035) and the CLINSH scenario (2035). It should be noted that this is a model outcome, assuming that policies are in place to overcome the financial barriers for the optimal options form the societal perspective. **It is not a prediction.** Ship owners may make different choices and for instance invest in after-treatment technologies or alternative fuels.

Table A3: Outcome C1 analysis: overview of technology distribution in the CLISNH scenario 2035. Based on lowest social cost scores, except for battery-electric (best social cost score but technologically immature).

Vessel type	Revision CCRO/1	Revision CCR2	Stage V	LNG mono fuel	LNG Dual fuel refit	SCR	SCR + DPF	Diesel electric	FWE	GTL
Passenger vessel <250 kW			79%							21%
Passenger vessel 250 - 500 kW			75%			22%				3%
Passenger vessel 500 - 1,000 kW			36%			27%	32%			5%
Passenger vessel >1,000 kW			100%							
Push boat 500 kW			100%							
Push boat 500-2,000 kW			97%				3%			
Push boat >2,000 kW			97%				3%			
Motor vessel <80 m length			91%							
Motor vessel dry cargo typical 80 & 86 m ship			97%				3%			
Motor vessel dry cargo typical 105 m ship			97%				3%			
Motor vessel dry cargo 110 m ship			97%				3%			
Motor vessel dry cargo >130 (135 m ship)			97%				3%			
Motor vessel liquid cargo 80-109 m (typical 86 m ship)			97%				3%			
Motor vessel liquid cargo 110 m ship			95%	2%			3%			
Motor vessel liquid cargo >130 (135 m ship)			97%				3%			
Coupled convoy			86%	1%			3%			
Ferry			24%	1%		37%				38%
Tugboat and workboat			52%			7%	25%			16%
Total			83%	1%		7%	4%			6%

* Note: Because of rounding, the rows do not always add up to a 100%.

Table A4: Outcome of C1 analysis: share of technology per scenario, for the Baseline 2020/2035 and CLINSH 2035 scenario.

Scenario	Unregulated	CCNR1	CCNR2	Stage V	LNG mono fuel	SCR + DPF	SCR	GTL
Baseline 2020	41.9 %	23.7 %	32.6 %	0.0 %	0.3 %	1.5 %	0.0 %	0.0 %
Baseline 2035	18.4 %	19.8 %	35.5 %	24.3 %	0.3 %	1.6 %	0.0 %	0.0 %
CLINSH 2035	0.0 %	0.0 %	0.0 %	88.6 %	0.0 %	0.0 %	1.7 %	9.7 %

* Note: Because of rounding, the rows do not always add up to a 100%.

Annex 4: Air quality modelling

CLINSH applied existing models using new input data gathered in the project to identify the inland shipping contribution to urban air quality for different emission scenarios in the cities of Antwerp, Rotterdam, Nijmegen and the greater Duisburg area (see Figure A4). It involves a consistent approach to derive land-based and shipping emissions to be applied in different air quality models. For reasons of brevity only the results for NO_x and only Rotterdam are presented in this annex; the results for PM and for the other model areas are similar.

Inland shipping emissions for all urban domains were prepared for the different scenarios as an input for different models. The line emissions were aggregated to area emissions with horizontal grid resolution of 1x1 km^2. Different air quality models were assessed to see if the emissions files could be used in these models and how these models compare. The model selected to calculate the effect of the scenarios on the air quality in Rotterdam is OPS-Pro edition 2020 version W-5.0.0.0. (Link)

Figure A4: The four areas for the air quality modelling in CLINSH

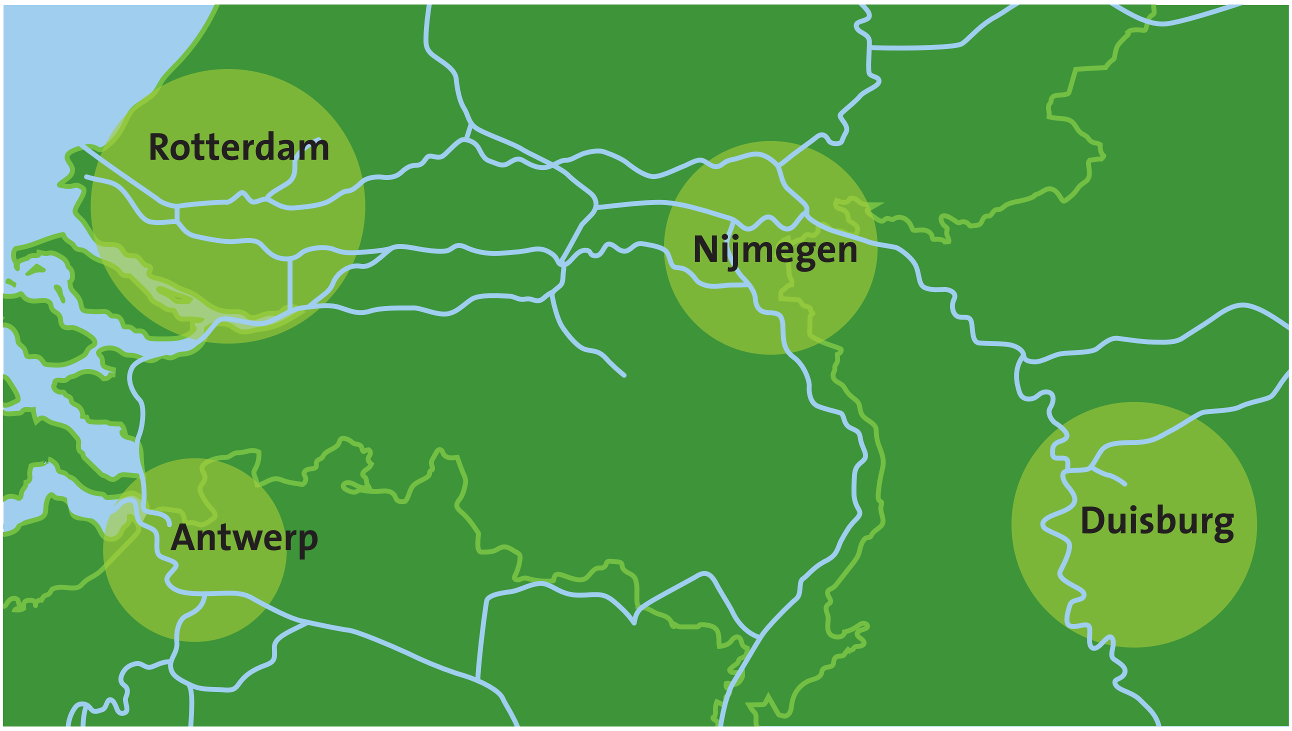
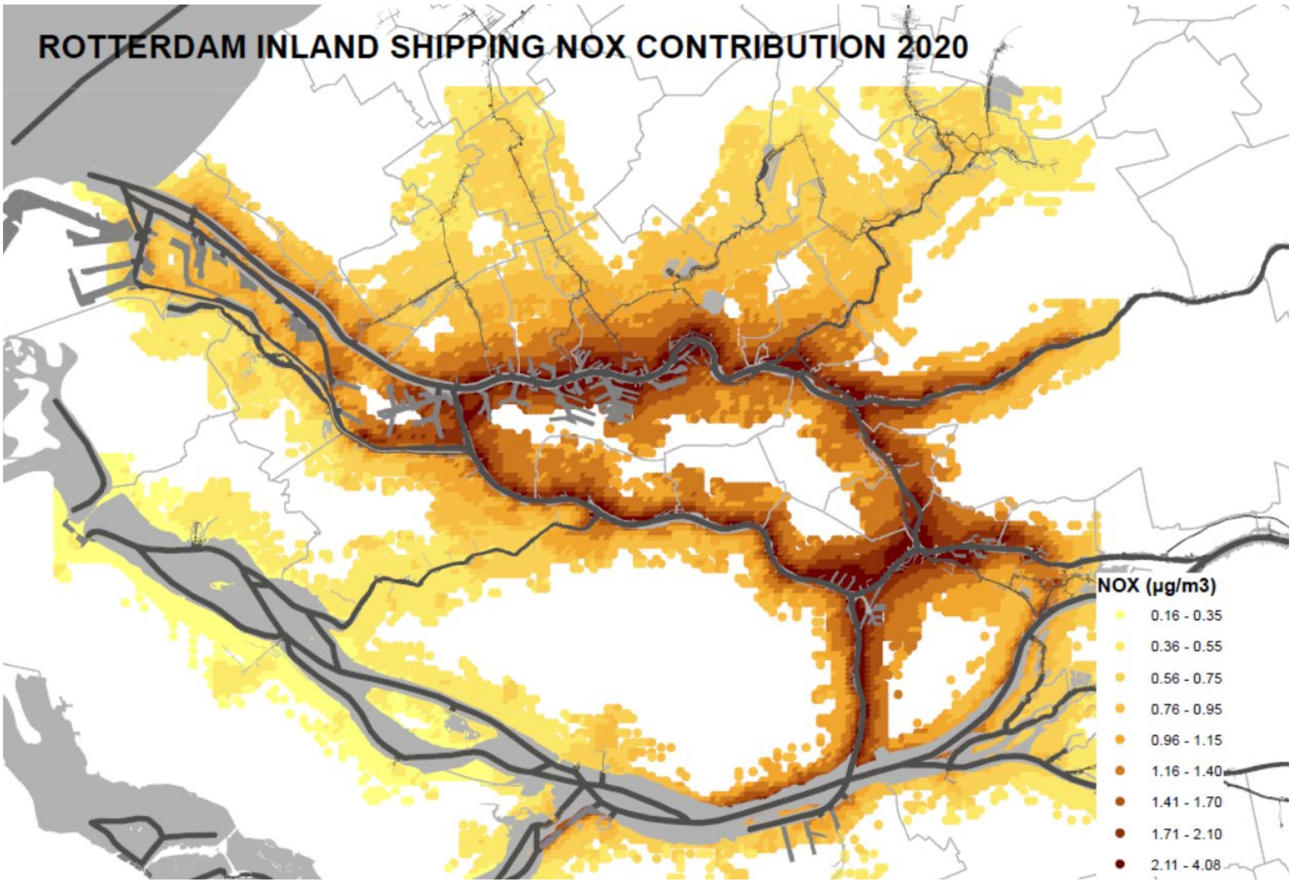


Figure A5: NO_x contribution from IWT in Baseline scenario for 2020.

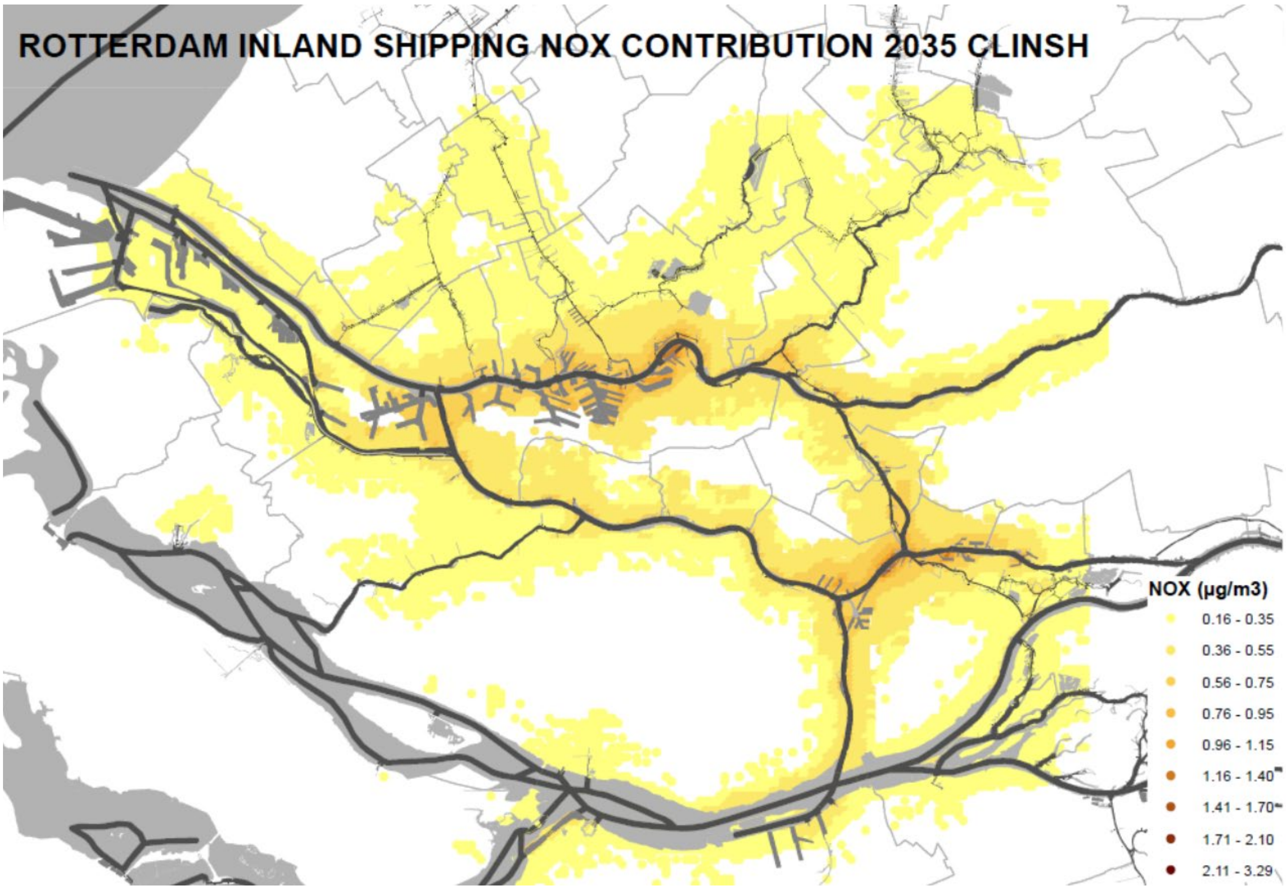


City	Component	Min	Max	Average
Rotterdam	NO_x	0.2	3.0	1.2

Figure A5 shows the NO_x concentrations in the Baseline scenario for the year 2020. Results are in NO_x and not NO_2 because the model is generally used for policy advice and not a chemical transport model.

NO_x concentrations can be converted to NO_2 concentrations in cases where there is a lot of information about the different emission sources, but the NO_x concentrations are more accurate so that in the Netherlands the NO_x concentrations are often used to show the effect of different measures. Roughly, about 50% of the NO_x concentrations is NO_2 in the Rotterdam area. In the Baseline scenario in 2020, inland shipping contributes between 0.2 to 3.0 µg/m^3 with an average of 1.2 µg/m^3.

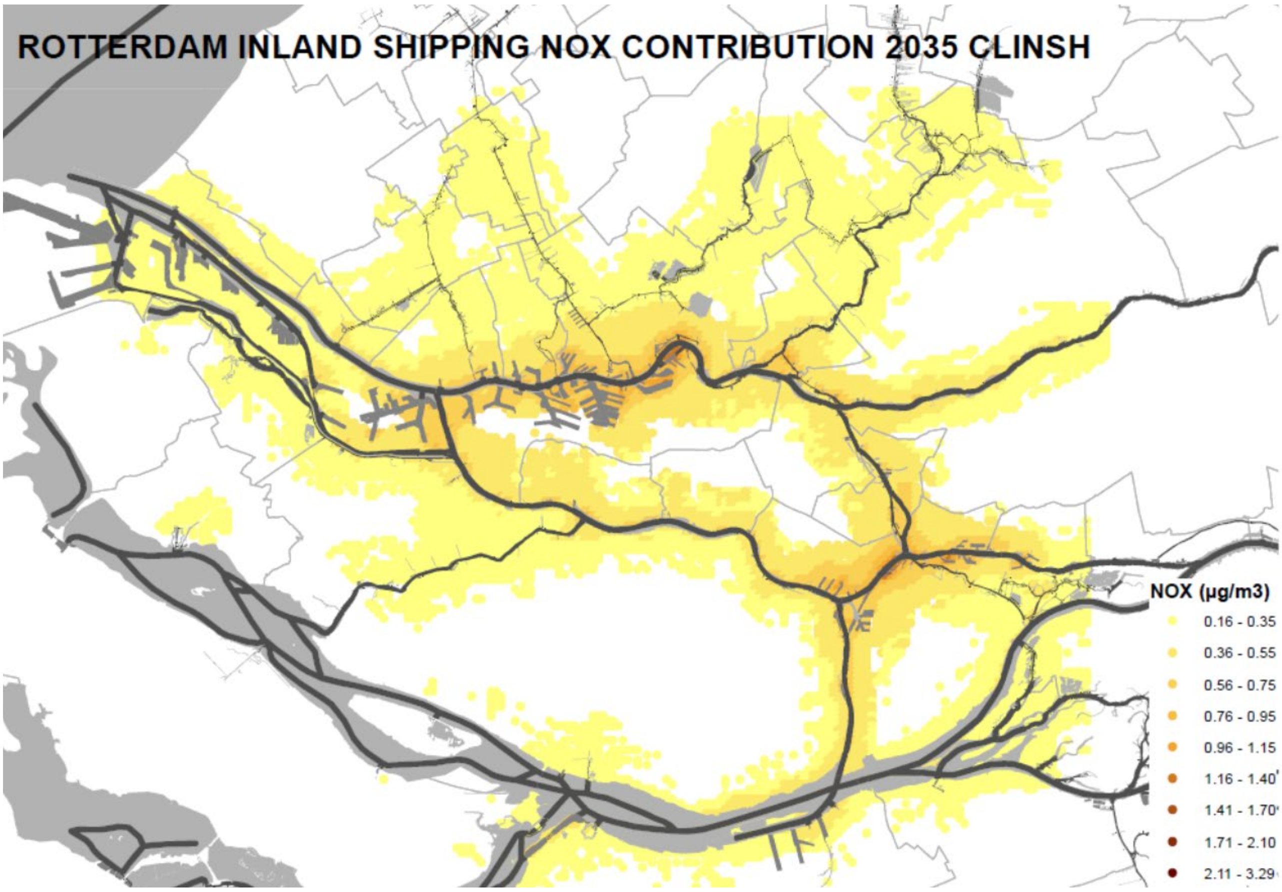
Figure A6: NO_x contribution from IWT in Baseline scenario for 2035



City	Component	Min	Max	Average
Rotterdam	NO_x	0.2	2.6	1.0

Figure A6: shows the contribution of inland shipping to the NO_x concentrations in the Baseline scenario in 2035. The contribution from IWT in the Rotterdam region varies between 0.2 and 2.6 µg/m^3 with an average of 1 µg/m^3. The contribution of the shipping is only slightly lower than in 2020.

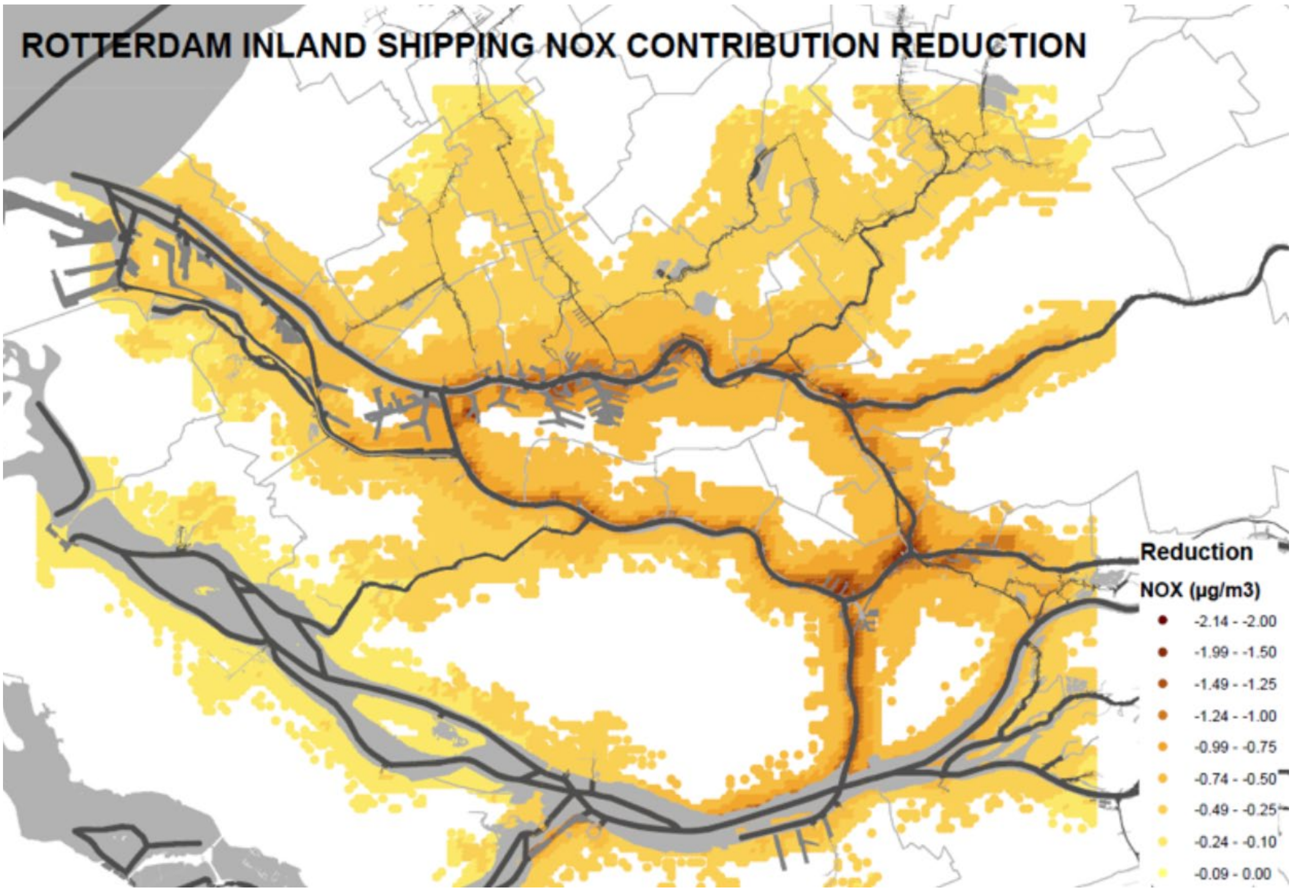
Figure A7: NO_x contribution form IWT in CLINSH scenario for 2035



City	Component	Min	Max	Average
Rotterdam	NO_x	0.1	1.3	0.4

Finally, figure A7 shows the contribution of inland shipping to the NO_x concentrations in the CLINSH scenario in 2035. The contribution from IWT to the NO_x concentrations in Rotterdam is significantly lower in the CLINSH scenario. The contribution varies between 0.1 and 1.3 µg/m^3 with an average of 0.4 µg/m^3.

Figure A8: NO_X reduction potential of the CLINSH scenario in Rotterdam region.



Scenario	Max	Average	Reduction vs. average Baseline 2020
Baseline 2020	3.0	1.2	–
Baseline 2035	2.6	1.0	16%
CLINSH 2035	1.3	0.4	66%

It is now possible to calculate the maximum reduction potential of the CLINSH scenario. Figure A8 shows the difference between the Baseline and the CLINSH scenario, in other words the "CLINSH effect". The reduction potential varies between 0.1 and 2.1 µg/m^3. The average drops from 1 µg/m^3 in the baseline scenario to 0.4 in the CLINSH scenario. In Rotterdam, close to the inland harbours where the houses are close to the harbour, a reduction potential between 0.13 to 1.5 µg/m^3 can be achieved. No local air quality measure has been able to accomplish such a strong effect so far.

Table A5 shows the amount of population that benefits from the CLINSH effect in Rotterdam. For over 150,000 inhabitants, the NO_x concentration decreases by 0.13 to 0.5 µg/m^3. For over 27,000 inhabitant the NO_x concentration decreases by 1.25 to 1.50 µg/m^3. Using the general rule of NOX/NO_2 conversion for the Rotterdam area, the NO_2 concentrations decrease with 0.62 to 0.75 µg/m^3 for these 27,000 inhabitants as a result of the realisation of the CLINSH scenario. The total population in the region is around 1.2 million people.

Table A5: The effect of NO_x reductions in the CLINSH scenario on the population of Rotterdam

Decrease of NO_x contribution µg/m^3	Inhabitants	Portion of Rotterdam population
-0.50 to -0.13	154,096	26%
-0.75 to -0.50	322,046	54%
-1.00 to -0.75	91,481	15%
-1.50 to -1.00	27,225	5%

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