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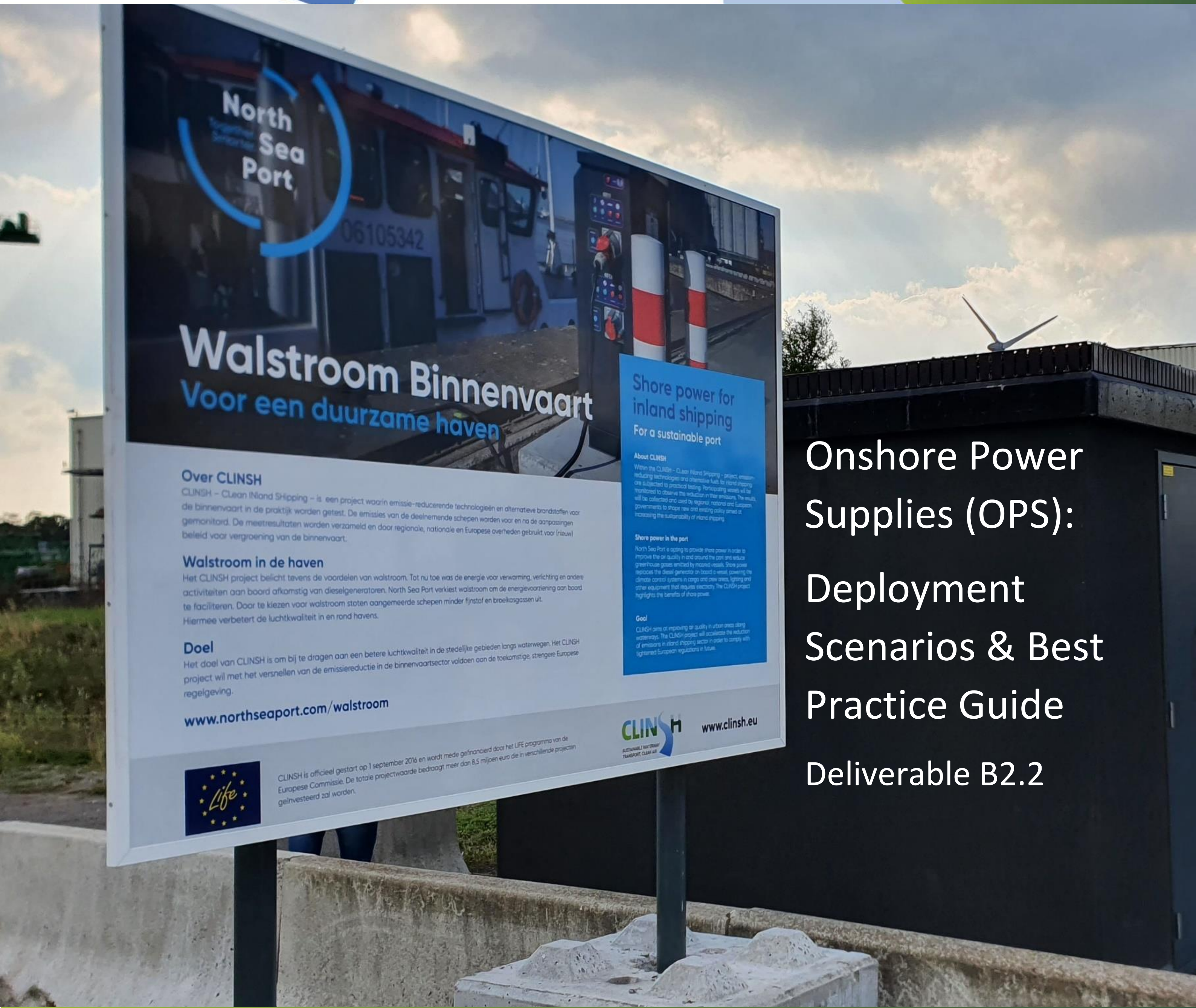
RELIABLE WATERWAY TRANSPORT, FRESH AIR



Onshore Power Supplies (OPS):

Deployment Scenarios & Best Practice Guide

Deliverable B2.2

CLEAN INLAND SHIPPING

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Project:	CLINSH – Clean Inland Shipping
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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Summary

In November 2017 the CLINSH consortium published a study on Port Characterisation and data collection on existing and planned Onshore Power Supply (OPS) in the Netherlands, Flanders, and North Rhine Westfalen. This deliverable (B.2.1) was later followed by a report on a market consultation on and technical/economic options review for onshore power supplies (deliverable B.2.2, October 2018), and a report on Standards and Regulations (deliverable B.2.3, October 2018).

Problem definition

This best practice guide is intended to assist stakeholders, including ports and local authorities, make the decisions concerning the deployment of Onshore Power Supply in Inland Ports. The guide includes deployment scenarios and several case studies of the CLINSH pilot OPS installations.

Background

Deliverable B.2.1, the port characterisation study, proposed a strategy for stakeholders using OPS as an instrument to improve air quality. The recommendations for the strategy were:

- invest in OPS where air quality and/or noise concerns are most pressing;
- and where the cost effectiveness of euros spent for emissions reduced is highest;
- we identified the top-5 type of locations;
- take into account that the business case for the ship owner should be at last neutral (this means: accept low OPS revenues);
- impose and enforce an auxiliary engine ban in the port wherever OPS is available;
- promote the use of OPS among ship owners (see measures from TEN-T Shore Power in Flanders) and their clients;
- use TEN-T funding for OPS in Core and Comprehensive ports and possibly other funding for other ports including recreational ports.

These recommendations were further validated in the market consultation in deliverable B2.2. The CLINSH consortium concluded that there are different technical solutions for OPS. The dominant solution is the grid connected OPS, which has a more positive business case than mobile OPS in most cases. Furthermore, the business case for river cruise vessels is more positive than the business case for cargo vessels. In line with the conclusions of deliverable B2.1. the consortium concluded that:

- The energy tax should be removed from OPS electricity. This brings the fuel in line with diesel supplied for inland vessels which is not taxed.
- 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.

- Payment systems should be made convenient for the skippers. 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.
- Generator bans should be introduced and enforced in ports. This would not necessarily require the use of OPS as vessels might have battery supplies available. It would reduce noise and air pollution.

Based on the market consultation and input from stakeholders, deliverable B2.3. focused more in depth on the standards and regulations. It was concluded that standardisation of shore power supply equipment is a prerequisite to enable ships to connect to onshore power electricity independent of the port at which they dock. The report identified several technical and operational factors to improve the utilisation of OPS:

- In the last decade more attention has been paid to the standardisation of OPS for maritime shipping. For inland navigation, a lack of international and EU-wide standards on connectors is still existing, which creates problems to ships that cross Member States' borders. A voltage standard is currently in place, but no standard connector. The connectors used in the Netherlands and Belgium may differ from those used in Germany. A better cooperation between ports and policymakers in different countries could be beneficial for the harmonisation of the connectors. The EC can play a crucial role herein.
- Convenience of the physical and operational system is also important. When reserving an OPS connection point, starting the electricity provision and payment of OPS is made as easy as possible (e.g. by means of smart-phone app, such as the free 'Walstroom power and water app), the numbers of OPS users may increase. Harmonisation of management and payment systems across Europe is assumed to increase the uptake of OPS.

Walstroom Power Point & App

- The OPS users claim that more berths and more OPS connections on ships are needed. When ships are side-by-side making the connection is especially difficult and sometimes for safety reasons not allowed. More OPS connections would allow increased use of OPS. The initiative lies here with the ports and local governments.

In term of regulation, the European Commission (EC) has studied the effects of using OPS in ports[1] and has drawn up several recommendations. Remaining challenges are discussed, and suggestions are made for who should be the action holder.

- The EU ports are in the focus of the EU regulations to deploy OPS. These regulations result mainly in high investment request to the ports. Strictly considering the return in terms of OPS cash flows, it appears that OPS is not really justifiable from a financial perspective. In order to make the desired investments in OPS possible, grants from the EC or from national programmes are necessary and/or existing financial reserves will have to be addressed. Policy makers should give more visibility to OPS in their financial instruments.
  In term of incentive regulations, a tax reduction on electricity used for OPS may promote the uptake op OPS. Some Member States have already used tax reduction on electricity to promote OPS, but efforts will not be effective enough as long as fuels for shipping are exempted from taxation. The EU's common framework for energy taxation – the Energy Taxation Directive or ETD should play a central role in guiding such initiatives. The proposal put forward by the Commission in July 2021 will alter the way in which energy products are taxed in the EU. They will remove outdated exemptions and incentives for the use of fossil fuels, for example in EU aviation and maritime transport, while promoting clean technologies. The new system will ensure that the most polluting fuels are taxed the highest.

- Other policy instruments might also be required, e.g. legislation and/or a market to trade carbon credits, which indirectly increases the costs of using diesel/heavy fuel oil. At national levels, port authorities should also consider port fees reduction for ships that use OPS.
- The sector is reluctant of any obligation to use shore power and of a possible generator ban, which is in place in several ports already. Member States should promote awareness of shore-side electricity among local authorities. What is needed is a culture change amongst skippers to comply with the generator ban without making enforcement of the ban an onerous task for the ports.
- National policy makers should encourage the development of a general communication strategy for OPS referring to the user friendliness and the ecological soundness of electricity when berthed.

[1] http://www.ops.wpci.nl/_images/_downloads/_original/1264083057_2006eucommissionrecommendationshoresideelectricity.pdf

- The EC encourages Member States to consider using financial instruments to facilitate OPS for ships in port, by exploiting the contingencies available in EU regulation. Current incentives do not always cover all costs and do not support companies equally. Governmental support is needed to ensure a broader implementation of OPS technology.

Contents

1 Introduction

Vessels using inland waterways emit air pollution from their fossil-fuelled engines: that is, engines used for propulsion and also engines used for generating ancillary power for use on the vessel (for pumps, cabin services, lighting, navigation etc). The CLINSH project aims to reduce all such emissions.

When a vessel is at berth, its propulsion engines are not running but its on-board generators are often needed to run continuously. This means that vessels are causing pollution when in port, which in turn impacts on air quality particularly in locations adjacent to the port. Provision of power to the vessel via a cable from shore can potentially eliminate this source of pollution.

The key objective of Action B2 is to assess the environmental and socio-economic benefits of onshore power supply (OPS) for the use of inland vessels and to develop guidance for the provision of grid-connected and mobile OPS which can help to justify investments. The action will demonstrate how OPS can improve air quality and aid compliance with emission limits. In this action we will give insights in the various business models, policy options, OPS installations and potential emissions reduction.

This best practice guide sets out scenarios to assist the decision-making process governing future OPS deployment sites, reflecting the impact of harmonisation and inter-operability on deployment levels. The environmental benefits of each scenario have been calculated. Case studies of the CLINSH pilot OPS installations in Gent and Nijmengen are included. The guide provides information for port and local authorities to select the appropriate OPS solution.

1.1 Target Audience

This Best Practice Guide is primarily aimed at inland waterway ports who have the responsibility to determine if and how they should invest in new OPS facilities. Much of the content of the Guide is focused on the performance of vessels. This is important for ports since it will determine the level of demand for OPS facilities. A critical question for ports is how they avoid investing in so-called 'stranded assets' – facilities that become obsolete due to unanticipated shifts in demand for vessel services. The Guide provides some insights into the key trends.

The attractiveness of OPS for vessel operators is very dependent on action by public authorities and governments. Without policy intervention, growth in usage of OPS will be slow. It is important that policymakers appreciate how policy options would impact on emissions and air quality. This is also targeted in the Guide.

The role of OPS within emissions reduction is part of a much broader megatrend driving innovation across the ports and shipping sector. Vessel builders and their supply chains are actively developing solutions for net-zero which will also transform the landscape for anti-pollution measures. The scenarios and impacts reporting in this Guide will also be relevant to future planning by those companies that build, equip, and maintain the inland waterway fleet.

2 Technology Available

2.1 Summary of the technical options for OPS

There is a range of options for provision of either fixed or mobile OPS. Grid connection is the simplest method with probably the best business case at present but there are other options, such as the hydrogen fuel cell or renewable energy systems, which in the long-term could offer emission free OPS.

As all-electric or hybrid inland waterway vessels become more common, expanding the MV grid in ports or buffering of the grid supply to provide rapid charging facilities is likely to be necessary with batteries often being the more economic option for this at the present time.

The table below summarises the overall technical options.

Summary of the technical options for OPS.

OPS Technology	Technology/ Commercial Readiness Level (TRL/CRL)	Flexibility	Technical Limitations	Economic Limitations
Grid Connected	9/5	Limited once installed but can have multiple connection points	None, as long as the vessel has the required protection systems	Location key to high utilisation and a positive business case. Electricity is taxed.
Mobile CNG	8/2	Mobile – portable to meet demand	Limited storage in CNG bottles	High transport cost of CNG
Mobile LNG	8/2	Mobile – portable to meet demand	Unproven for inland vessels, none in principle	High cost of transport for LNG if no filling/bunkering station
Diesel Engine	9/6	Mobile – portable to meet demand	Unlikely to reduce emissions	More expensive than on board generation
Biodiesel Engine	8/3	Mobile – portable to meet demand	Biodiesel blends have been used	More expensive than pure diesel
Glycerol fuel	7/1	Mobile – portable to meet demand	None although not run as OPS	Expensive – high cost of fuel and fuel transport
Hydrogen Fuel Cell	7/2	Mobile – portable to meet demand	Depends on hydrogen availability	Likely to be expensive
Renewable Energy	7/2	Likely to be a fixed system, if the renewable energy devices are grid connected	None in principle, would require assessment of available renewable energy. Battery lifetime limited.	Likely to be an expensive solution but there is potential to sell electricity even when OPS not in use if grid connected.
Battery charging – buffered supply	9/2	Limited	Batteries would require periodic replacement	Batteries likely to be cheaper than supercapacitors
Battery charging – unit exchange	5/1	Fixed locations	OPS simple	OPS should be as for grid connected
Battery charging – fast charge MV supply	2/1	Limited locations	Need impact study for local grid supply	Electricity cheaper from MV than LV

Although the majority of OPS systems currently in use are fixed location, grid connected supplies, there is a range of other options that can be used to provide OPS connections. These options are discussed in the sections below, followed by consideration of the technology readiness levels of the different systems.

The European Standard sets out the requirements for an OPS system for inland waterway vessels, as shown in Figure A, with the key to the figure provided in Table A (BSI, 2019a)[2]. The Standard also sets out the safety requirements of an OPS unit. Figure B and Table B detail the required shore-side protection equipment (BSI, 2019b)[3]. For each arrangement the basic requirements in terms of protection equipment would be the same: the essential difference is in the source of the electrical supply. The alternatives can be viewed in terms of their flexibility and adaptability for different locations and installations, their technical limitations, and also their Technology Readiness Levels (TRL)4, as detailed in Table C(a), or their Commercial Readiness Index (CRI), as outlined in Table C(b).

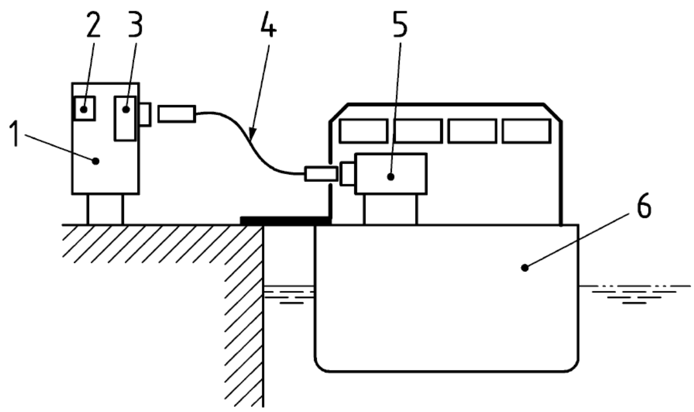


Figure A: Elements of an OPS supply, as detailed in the European Standard. (BSI, 2019a)

Table A: Key to the OPS system shown in Figure A. (BSI, 2019a)

Item	Description
1	Power Supply Station
2	Operating Instructions
3	Shore Connection Unit
4	Shore Connection Cable
5	Feeding Unit, Type B
6	Inland Navigation Vessel

[2] BSI (2019a) BS EN 15869-1:2019 Inland navigation vessels – Electrical shore connection, three phase current 400V, 50Hz, up to 125A. Part 1: General Requirements. London: British Standards Institution.
[3] BSI (2019b) BS EN 15869-1:2019 Inland navigation vessels – Electrical shore connection, three phase current 400V, 50Hz, up to 125A. Part 2: On-shore unit, additional requirements. London: British Standards Institution
[4] https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf

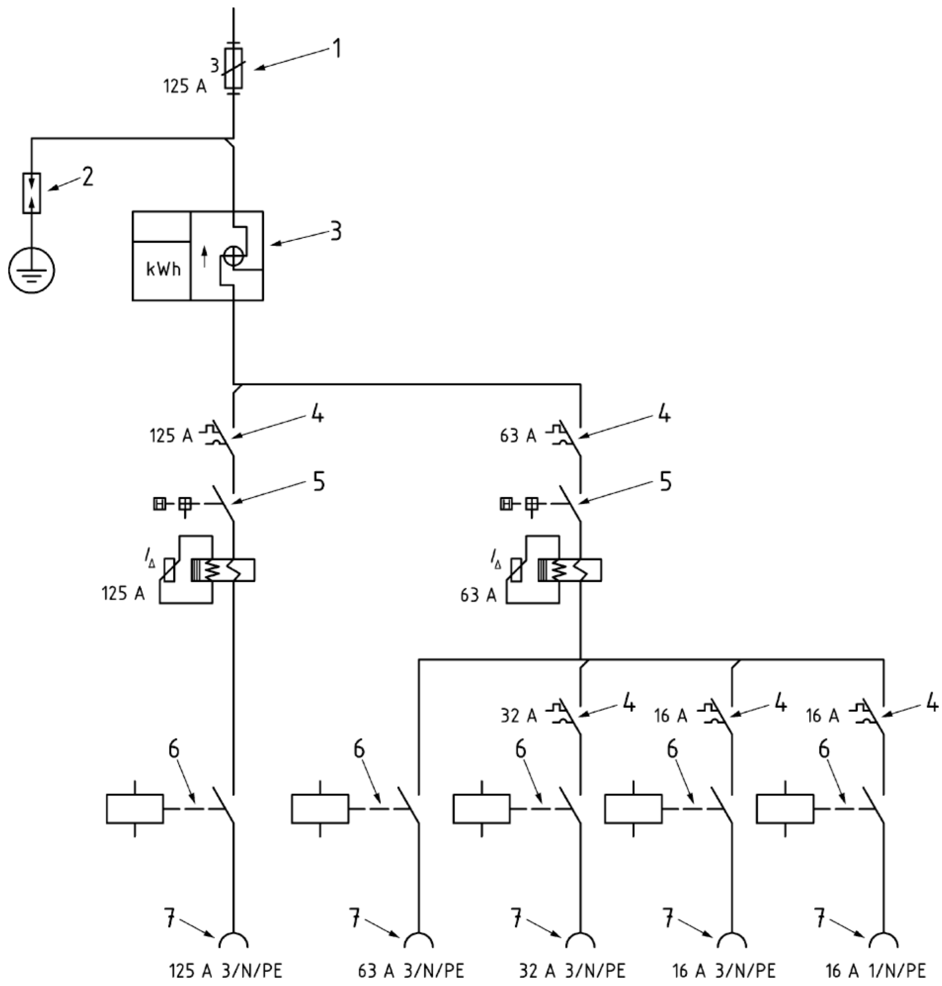


Figure B: Protection requirements for a shore-side OPS unit with two output voltages. (BSI, 2019b)

Table B: Key to the OPS protection system shown in Figure B. (BSI, 2019b)

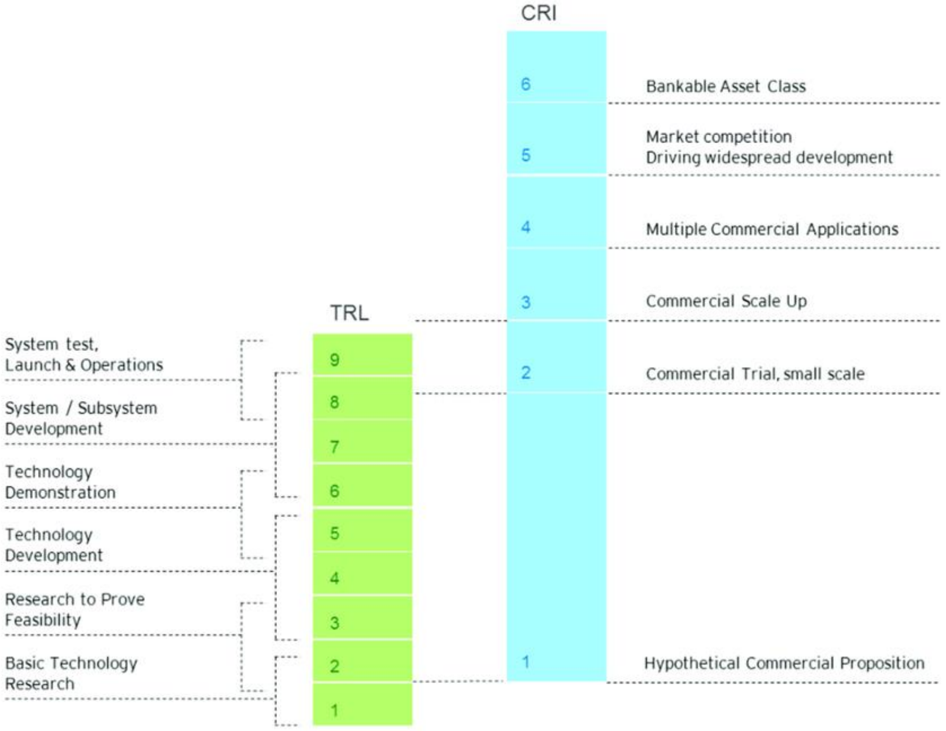
Item	Description	Item	Description
1	Line Protection Fuse	5	Residual Current Operated Circuit Breaker
2	Overvoltage Protection	6	Activation Medium for Release
3	Three Phase Meter	7	Socket Outlet
4	Circuit Breaker		

Table C(a): Definitions of Technology Readiness Levels. (NASA)

Technology Readiness Level	Definition
TRL1	Basic principles observed and reported
TRL2	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL4	Component/subsystem validation in laboratory environment
TRL5	System/subsystem/component validation in relevant environment
TRL6	System/subsystem model or prototyping demonstration in a relevant end-to-end environment
TRL7	System prototyping demonstration in an operational environment
TRL8	Actual system completed and "mission qualified" through test and demonstration in an operational environment
TRL9	Actual system "mission proven" through successful mission operations

Table C(b): Definitions of Commercial Readiness Index. (ARENA, 2014)

Commercial Readiness Index	Definition
CRI1	Hypothetical commercial proposition (equiv. TRL 1-7)
CRI2	Commercial trial, small scale (equiv. TRL 8-9)
CRI3	Commercial scale up
CRI4	Multiple commercial applications
CRI5	Market competition driving widespread development
CRI6	Bankable asset class



2.2 Grid connected OPS

As noted previously, the majority of OPS systems currently offered are grid connected. These are typically single phase, 230V/16A supplies or three phase, 400V/32A/63A/125A with a 400A output available for river cruise vessels in some cases.

Although there can be issues with making a positive business case for grid connected OPS, the technology is mature and readily available. Given the power levels drawn by typical inland waterway vessels - an average of around 200kW for river cruisers and 40kW for cargo ships (Hoogma, et al., 2017), the provision of grid connected OPS will have little impact on the power quality of the local grid supply.

With regard to emissions, use of grid connected OPS will generally reduce airborne emissions in the port area, however the overall benefit of such a system will depend on the source used for the electrical generation plant in a particular country or region (Hall, 2010). If grid electricity is generated using renewable or nuclear energy then there will be a significant reduction in overall airborne emissions, however extensive use of coal-fired generation plants may simply displace the air quality problem from the port to the area surrounding the power station, depending on the quality of coal used and the technology of the power plant (Hoogma, et al., 2017).

Grid connected OPS is summarised in Table D.

Table D: Summary of grid connected OPS.

TRL/CRI	9/5
Flexibility	Limited once installed but can have multiple connection points from one cabinet
Technical limitations	None, as long as the vessel has the required protection systems
Economic limitations	Given the inflexibility of an installation, location is key to ensuring high utilisation and a positive business case. Electricity used is taxed.

2.3 CNG/LNG powered OPS

As reported in B2.1 (Hoogma, et al, 2017), a pilot study was conducted in the port of Nijmegen using a mobile OPS unit with a micro-turbine fuelled with compressed natural gas (CNG). Although the system functioned well from a technical perspective and almost without noise, there were issues raised regarding the logistics and business case for such a unit. The system would supply power for approximately two days between refuelling but the transport costs for the bottles of CNG are relatively high, making the arrangement uneconomic.

Liquefied natural gas (LNG) is an alternative to CNG to extend the time between refuelling and the option exists to use an additional tank to store LNG next to the OPS unit. However, again the transport costs for LNG would be prohibitive unless there was a filling station nearby.

Both the Ports of Hamburg[5] and Rotterdam have used mobile LNG solutions to provide OPS for sea-going ships. In such a system, the barge carrying the LNG-OPS generator could be floated to a berth at which the LNG tanks could be refilled, thus reducing transport costs. However, at present this has only been used for the relatively high power demands of sea-going ships and it would be difficult to make a business case for such an arrangement at the power levels required by inland vessels unless the barge was supplying multiple ships at a given time.

The use of CNG and LNG for inland waterways OPS is summarised in Tables E and F respectively.

Table E: Summary of CNG powered OPS.

TRL/CRI	8/2
Flexibility	Mobile solution; generator and cabinet could be moved to assess demand for OPS at different berths
Technical limitations	Limited storage in CNG bottles, require replacement every ~2 days
Economic limitations	High transport cost of CNG makes business case difficult

Table F: Summary of LNG powered OPS.

TRL/CRI	9/3 for sea-going ships, 8/2 for inland waterways
Flexibility	Mobile solution that could be moved to different berths or barge-based system that could be floated to where it is required
Technical limitations	None for sea-going, unproven for inland vessels but no barriers in principle
Economic limitations	High cost of transport for LNG unless truck filling station or bunkering station available at port for barge

[5] https://future.hamburg/en/project/lng-hybrid-barge/

2.4 Diesel engine powered OPS

One of the issues with ships operating their engines to generate electricity in port is that, unless the ship has a small generator specifically for port operations, the engine is likely to be running lightly loaded. If this is the case then the specific fuel consumption will be relatively high, as will the airborne emissions. An option to overcome this would be to provide an OPS supply generated from a small diesel engine onshore; however, variability in the power demand of different ships may mean that the engine would be oversized in many cases and therefore would simply be reducing the running hours of the ship's engine, rather than solving the problem.

On the positive side, a shore-based diesel engine could be soundproofed to avoid transmission of noise pollution to local residents. In addition, filters and scrubbers could be fitted to improve the quality of the exhaust emission, although this would increase the capital cost of the system, making the business case more difficult.

The river cruise company Viking operated diesel engine powered OPS in its winter port in Cologne but stopped because of high costs, before changing to grid connected OPS (Hoogma, et al., 2017).

A further option would be to utilise biodiesel in the OPS engine system, however, as with CNG and LNG, unless this is already available at the port, the fuel and transportation costs would potentially be too high to make this viable.

The use of a shore-based diesel engine to supply OPS is summarised in Table G.

Table G: Summary of diesel engine powered OPS.

TRL/CRI	9/6 (possibly lower for use of biodiesel although there are generators using biodiesel blends)
Flexibility	Mobile solution; generator and cabinet could be moved to assess demand for OPS at different berths
Technical limitations	None in terms of operation but emissions are unlikely to be significantly reduced if power drawn from the OPS is low
Economic limitations	More expensive solution than on board diesel generator. Biodiesel is more expensive than diesel.

2.5 Alternative fuels such as Glycerol for OPS

Glycerol is a by-product of the manufacture of biodiesel and can be used as a fuel for a modified diesel engine with very low emissions according to laboratory testing (Aquafuel, https://www.aquafuelresearch.com/glycerine-chp.html). It was found, during the CLINSH project, that the cost of electricity generated from glycerol would typically be around €0.20/kWh which is significantly more than the €0.12/kWh currently being paid for grid electricity from a low voltage connection. Given that the capital cost would be the same as for a standard, diesel-powered generator, the business case for a grid connected OPS arrangement would be significantly better.

In addition, although glycerol is produced in large quantities globally, it is not generally available in port areas and would therefore have transport costs associated with its provision for OPS.

The use of a glycerol-fuelled diesel engine to supply OPS is summarised in Table H.

Table H: Summary of glycerol-fuelled diesel engine OPS.

TRL/CRI	7/1 (glycerol has been demonstrated as a fuel but not in OPS application)
Flexibility	Mobile solution; generator and cabinet could be moved to assess demand for OPS at different berths
Technical limitations	None in terms of operation of the engine
Economic limitations	Likely to be an expensive solution given high cost of fuel and transport costs to deliver it to the port.

2.6 Hydrogen fuel cell powered OPS

In 2017, the Orkney Islands in Scotland began development of a hydrogen fuel cell powered OPS system for ferries (EMEC, 2017; Surf 'n' Turf[6]). Electricity from a community-owned wind turbine and tidal energy devices under test at the European Marine Energy Centre, is used to power an electrolyser which produces the hydrogen which, in-turn, is used for a 75kW fuel cell. In 2021, Orkney generates 120% of the local power demand from renewable sources, business models are in development to export some of this excess in the form of hydrogen.

Low temperature fuel cells, such as the proton exchange membrane (PEM) fuel cell, are supplied with hydrogen and oxygen which are combined internally to produce electricity and water. There are no other emissions from the process and since fuel cells have few moving parts (only fans and pumps), they operate at much lower noise levels than other mobile OPS options such as small diesel engines. They would therefore offer a good fit for inland waterway OPS in producing no emissions or noise pollution.

An ongoing project to develop and demonstrate a hydrogen fuel cell powered mobile OPS unit in the Green Shipping Waddenzee project, involving the Dutch northern ports and companies in the region. The 335 kW unit will be tested for maritime and inland vessels.

Whilst tidal energy would not be available to inland waterway ports, there is no reason why hydrogen could not be generated locally using other renewable sources such as wind or solar. This would remove the transport cost for the fuel although, at the present time, fuel cells are unlikely to offer a cost-competitive option for inland waterway OPS.

The use of hydrogen fuel cell OPS is summarised below.

Summary of hydrogen fuel cell powered OPS.

TRL/CRI	7/2 (all of the elements exist at TRL 9 but the overall system is unproven for inland waterways)
Flexibility	Renewable energy devices and electrolyser are likely to be static but the fuel cell could be a mobile solution for OPS
Technical limitations	None in principle but would require assessment of available renewable energy
Economic limitations	Likely to be an expensive solution given the need for renewable energy devices, electrolyser, and fuel cell.

[6] https://www.emec.org.uk/projects/hydrogen-projects/surf-n-turf/

2.7 Renewable energy powered OPS

An alternative to using renewable energy to produce hydrogen would be to use the generated electricity directly to power the OPS system. The majority of renewable energy sources fluctuate and therefore would have to be used in conjunction with battery storage or the grid supply in order to provide a steady output to the OPS users. Wind turbines or solar photovoltaic modules would be the most likely choice for generating electricity close to inland waterway ports with the specific choice depending on the available resource.

Under the CleanMobilEnergy INTERREG project (2018-2021), (http://www.nweurope.eu/projects/project-search/cleanmobilenergy-clean-mobility-and-energy-for-cities/) the City and Port of Arnhem have developed a solar powered OPS system. The OPS cabinets in the industrial port, where river cruise vessels are berthed over the winter, will be connected to 10MWp of solar panels and a battery storage system to power the vessels. Whereas in Nijmegen, the solar panels on top of a factory building provide power to OPS cabinets in the industrial port in addition to the nearby residential area (without battery storage).

An OPS system and the renewable energy devices might reasonably be expected to operate for 25 years, however typical battery lifetimes are 5-10 years so there would probably need to be two replacement battery units over the lifetime of the OPS. Alternatively, the renewable energy devices could be grid connected, selling electricity back to the grid when the OPS demand is low and using the grid to buffer the fluctuations of the renewable generation. In this second case, there would obviously be greater capital investment for the port or companies in the port compared to the simple grid connected system, but there is the potential for the port or companies to have an income from the renewable devices whether or not the OPS is in use; this would depend on the local regulations regarding selling electricity back to the grid, however.

The use of renewable energy powered OPS is summarised below.

Summary of renewable energy powered OPS.

TRL/CRI	7/2 (all of the elements exist at TRL 9 but the overall system is unproven)
Flexibility	Likely to be a fixed system, particularly if the renewable energy devices are grid connected
Technical limitations	None in principle but would require assessment of available renewable energy. Battery lifetime will be limited.
Economic limitations	Likely to be an expensive solution but there is potential to sell electricity even when OPS not in use if grid connected.

2.7.1 Integration with smart port energy systems with integral renewable energy generation and storage.

The section above on the use of renewable energy for OPS, can be linked to the concept of smart port energy systems. Essentially, the smart port energy concept is centred around reducing the environmental impact or ports and port operations. This includes reducing greenhouse gas emissions through a combination of demand reduction and use of renewable energy sources as well as reducing air, water, and noise pollution to limit the impact of the port on its neighbouring communities. The technology links renewable energy and energy storage with an energy management system through smart grid infrastructure, as in the abovementioned Arnhem example.

Electrification of port equipment like cranes and terminal tractors would be one element of such a development, but OPS would also play a key role. Installation of renewable energy generation, most probably solar photovoltaics, and wind turbines for ports on inland waterways, would allow vessels to reduce their air and noise pollution essentially to zero whilst alongside.

The Port of Rotterdam has been involved in a research project about integrating renewable energy into the port supply network (Smart Port, 2020) to increase the sustainability of their operations. Whilst this is for a large port with both sea-going and inland vessels, the technology solutions would be scalable to smaller, inland waterways ports.

The use of smart port energy solutions and renewable energy powered OPS is summarised below.

Summary of smart port energy solution with renewable energy powered OPS.

TRL/CRI	7/2 (many of the elements exist at TRL 9 but the overall system is unproven for inland waterways)
Flexibility	Likely to be a fixed OPS system
Technical limitations	None in principle but would require assessment of available renewable energy. Battery lifetime will be limited.
Economic limitations	Likely to be an expensive solution but would lead to overall port sustainability.

2.8 Battery charging OPS with and without supply buffering **Error! Bookmark not defined.**

Some equipment suppliers are now offering OPS solutions for battery charging on hybrid and all-electric vessels. These systems are grid connected with local energy storage, such as batteries, to buffer the grid. Particularly where rapid charging of the ship's battery is required, the power drawn in charging the battery is significantly higher than that of a typical inland waterway OPS system, and could have a negative impact on the local supply quality. The energy buffer charges slowly from the grid and then releases its energy rapidly to recharge the ship's battery.

An alternative system which has been developed by Zero Emission Services (ZES) is the development of an all-electric barge with a containerised battery solution (Boffey, 2018; Ship & Bunker, 2018a). In this case, discharged batteries on the vessel would be replaced with fully charged ones whilst the ship is in port and then the batteries can be recharged without the need to use rapid charging systems. The first ZES charging stations in Alphen aan den Rijn entered service in September 2021. The container vessel Alphenaar is the first ship to sail with the ZES swappable batteries system. ZES's ambition is to realise 30 zero-emission shipping routes by 2030. Having also initially proposed swappable containerised batteries, Portliner have since shifted to flow battery systems.

Alternatively, rapid charging of batteries can be provided from medium voltage supplies through power electronic converters, without the need for buffering. Studies would be needed into the grid impact of fast charging of inland waterways vessels looking at the potential up-take of fast charge-capable inland waterway vessels and locations for fast charge points and the local grid infrastructure, to assess likely impacts and economic feasibility. Fast charge for vessels has been demonstrated for fjord ferries in Norway and river ferries in the Netherlands.

The use of buffered grid supplies for battery charging OPS; battery exchange and medium voltage fast charging are summarised in the tables below.

Summary of buffered grid supplies for battery charging OPS.

TRL/CRI	9/2 (in use for small sea-going ferries)
Flexibility	Likely to be a fixed system
Technical limitations	Batteries would require replacement within the lifetime of the overall system
Economic limitations	Battery likely to be lower cost than supercapacitor alternative in the short-term.

Summary of battery exchange system.

TRL/CRI	8/2 (overall system ready for demonstration)
Flexibility	Battery exchange and recharge at fixed locations
Technical limitations	Batteries would require replacement within the lifetime of the vessel but OPS would not require buffering
Economic limitations	OPS should not be expensive as no rapid charging required

Summary of medium voltage fast charging OPS.

TRL/CRI	9/5 (for road vehicles) 8/2 (first applications for ferries, for other inland waterways as yet to be developed)
Flexibility	Fixed system and limited to locations where MV supply available
Technical limitations	Studies required to look at the impact of fast charging on the local grid supply
Economic limitations	Electricity at MV is lower cost than LV supply but fast chargers require considerable investment

3 Status of OPS Today

3.1 Deployment in Inland Ports

3.1.1 Arnhem-Nijmegen Best Practice Case Study

This section presents best practices from the Arnhem Nijmegen city region. These best practices, discussed earlier in CLINSH deliverable B2.1 (2017) and updated for this guide, are chosen because of their policy implications. For a comprehensive analysis we kindly refer to deliverable B2.1.

For the purpose of this best practice guide we will elaborate on:

- OPS solutions in Arnhem and Nijmegen for (mainly) river cruise vessels and hibernating vessels
- Examples of OPS solutions on private quays

3.1.1.1 Introduction OPS in Arnhem-Nijmegen region

The Arnhem Nijmegen City Region is situated at the heart of a metropolitan area in the east of the Netherlands. The region is flanked by the Randstad conglomeration (west), the Brabant cities and Flemish Diamond (south), and the Ruhr area conglomeration (east). The region has a total population of more than 750,000 inhabitants. The cities of Arnhem and Nijmegen are the focal points of the region, both in terms of inhabitants and economic activity.

One of the unique characteristics of the region is the presence of waterways. The German Rhine, after crossing the border, divides into the Rhine (along Arnhem) and Waal (along Nijmegen) that flow west towards the seaports of Rotterdam and Amsterdam. The Ijssel branches off the Rhine at Arnhem and flows north via Doesburg. Inland waterways are an important modality for the transportation of goods. 2.1 million TEU containers and 141 million tonnes of goods were transported on the river Waal across the German and Dutch border yearly. This equals 125,000 ship movements.

Inland waterways are not only vital for the economy from a transportation perspective, they also function as a recreational mode for river cruises. The Arnhem Nijmegen region has a strong recreational sector and the cities Arnhem and Nijmegen function as boarding places for river cruises along the Rhine and even up the Danube.

3.1.1.2 Policy focus: improving Air Quality

Inland waterway transport is one of the cleanest modes of transport per unit of cargo, but it still constitutes a significant part of the emissions in the region. Public bodies in the region have developed policy measures to decrease the emissions of inland shipping and to improve the air quality in the region. Policy measures were funded by the national programme on air quality and other programmes. Since 2011 the region developed policy measures to improve the air quality for the inland waterway transport mode. The programme functioned to help ship owners and waterfront industry to invest in measures to decrease the emissions by ships and also funded public investments in Onshore Power Supply in Arnhem and Nijmegen.

3.1.1.3 Overview: Onshore Power Supply in Arnhem Nijmegen City Region

Table 4.1 shows the existing publicly (co)-funded OPS in the Arnhem Nijmegen City Region. Included are also three ports of distress along the Waal and IJssel that are being renovated or newly constructed on behalf of Rijkswaterstaat (national Department for Public Works and Waterways). Just outside the region the town of Wageningen has also made OPS available for freight ships staying overnight (not included in this case study).

For the selected case studies, we describe the following aspects: policy background, implementation and current usage, the business case and opportunities to increase the use of OPS.

Table 4.1 OPS in Arnhem Nijmegen City Region: existing and planned (updated October 2021)

Onshore Power Supply in Arnhem Nijmegen City Region				
Location	City	Ownership	Connections	Target group
Waalkade	Nijmegen	Public	4 cabinets with each 12 connections.	River cruise and freight ships (short stay)
Waalhaven	Nijmegen	Public	16 connections on high water-level jetty	Freight ships, overnight (long stay)
Lindenberghaven and eastern Waalkade	Nijmegen	Public	1 multi-use cabinet for events and recreational ships	Recreational ships
Container Terminal Nijmegen	Nijmegen	Private	2 cabinets with 1 connection each	Container ships
Kanaalhavens	Nijmegen	Private	5 publicly accessible grid connected OPS cabinets. 14 connections.	Freight ships, overnight (long stay), hibernating river cruises.
Nieuwe Kade	Arnhem	Public	5 cabinets with 2 connections each	River cruise
Nieuwe Haven	Arnhem	Public	3 cabinets, 16 connections total	River cruise (hibernating)
Container Terminal Doesburg	Doesburg	Private	1 cabinet with 1 connection	Containerships
Port of distress along Waal river	Lobith (Tuindorp)	Public	Realisation planned for 18 berths	Freight ships, overnight (long stay) free of charge
Port of distress along Waal river	Spijk (Beijenwaard)	Public	Realisation planned in 2023 for appr. 50 berths	Freight ships, overnight (long stay)
Port of distress along IJssel river	Giesbeek	Public	Realisation planned in 2023 for 17 berths	Freight ships, overnight (long stay)

3.2 Case Study: Arnhem-Nijmegen River Cruise OPS

3.2.1 Policy background

The cities of Arnhem & Nijmegen had an extensive air quality programme to meet the air quality standards in 2017. Besides policy measures for road transport (passenger and freight) and industry, the cities together developed policy measures for the reduction of emissions from inland waterway transport. Next to the realisation of OPS, a broader policy package was developed which included an on-board generator ban on places where free connection to OPS is available, differentiation of port dues for clean vessels according to the "Green Award" certification, development of a LNG bunkering site on the Waal and a subsidy scheme for low-emission shipping technologies.

Example of an OPS cabinets in Arnhem and Nijmegen

3.2.2 Implementation and usage

OPS was installed with a grant from the national air quality programme (NSL) in several locations in Arnhem and Nijmegen. At the Waalkade (quay) in Nijmegen 4 OPS cabinets were installed where both river cruise ships, and inland waterway freight ships can be connected. These cabinets have 12 connections for 230 V/16A, 400 V/32A, 400V/63A and 400V/125A, and each cabinet also has a Powerlock connection (400Volt/400A). A single cabinet can connect multiple cargo ships at the same time, or one river cruise ship. In Arnhem OPS was realised on the Nieuwe Kade and more recently (2019) in the Nieuwe Haven.

The target group for the use of OPS in Arnhem and Nijmegen is the same at the Waalkade and Nieuwe Kade but differs for the Nieuwe Haven. OPS in Arnhem's Nieuwe Haven is mainly used during the winter season for hibernating river cruise vessels, whereas at the other locations OPS is mainly used during the summer tourist season. Both Arnhem and Nijmegen currently have a generator ban in place in locations where OPS is available. In 2019 a total of approximately 1 million kWh was delivered to ships in Arnhem, and more than 500,000 kWh in Nijmegen.

Interesting in this case study is the possible impact of high water and that the quay may overfloat several times a year. OPS cabinets should then be dismantled and temporarily removed.

For Nijmegen it was concluded that, in hindsight, the procurement of OPS was done from a predominantly technical perspective. Little practical (operational) feedback was gathered before the tender and therefore different operational / technical issues caused negative experiences among skippers during the start of OPS in Nijmegen. These technicalities could have been prevented when the tender documents would have been discussed with skippers and market parties in a market consultation. In general, however, the municipality of Nijmegen is satisfied with the OPS.

Nijmegen concluded a service contract for the Waalkade with the company walstroom.nl (Involtum) to provide a payment platform, connection/uptime for the meters, administration, invoicing and helpdesk. Nijmegen takes care of the management & maintenance itself. Nijmegen does not have a service contract for the other public quays in Nijmegen (Waalhaven and Lindenberghaven); here the municipality organises the payment, administration and invoicing etc. itself. The Waalhaven is used mainly by Nijmegen-based skippers and crews during the Four Days Marches festivities and over Christmas time, whereas the Lindenberghaven is a recreational port. In Arnhem these administrative services are delivered by the company Park-Line Aqua.

3.2.3 Business case

The economic business case for OPS in Nijmegen is negative. The initial investments were approximately € 1,000,000. 50% co-funding was obtained from the air quality programme, which significantly decreased the investment costs for the municipality. No exploitation model was made before the tendering and Nijmegen does not calculate depreciation costs.

The costs for management & maintenance have not structurally been attributed to the exploitation of OPS, but maintenance (repairs) usually costs € 4,500 a year. A fixed fee of € 1,150 per quarter is paid for the service contract for the operational platform. Nijmegen also pays for the electricity purchase and the energy taxes.

The city is paid 27.45 eurocents per kWh (incl. 21% VAT) by the OPS service provider. This rate was not based on a business model calculation but is the same as the usual rates for OPS in the Netherlands.

This leads to the following indicative business case (using figures for 2016).

Gross revenue (226,000 kWh)	€ 49,000
Costs of electricity purchase (€12 ct/kWh)	€ 27,000
Net revenue	€ 22,000
Annual repair costs	€ 4,500
Operational platform	€ 1,150
Depreciation (10 years, excluding interest)	€ 50,000
Net result exploitation	-€ 33,650

However, if we look at the actual usage in 2019 (around than 350,000 kWh) the gross revenue would be around €75,000 euro and the cost of electricity would rise to around €40,000. This would close the gap in the exploitation by a third.

When adopting the calculation method for societal and environmental benefit applied to OPS in the Port of Antwerp, the 2016 benefit of OPS in Nijmegen is € 31,977. So, the costs of providing OPS were already in 2016 more or less balanced by the societal and environmental benefit, and there was a clear benefit in 2019.

OPS in Arnhem has a different cost structure but with a yearly average usage of around 1 million kWh in 2019 it could be argued that there is a positive business case from a city's perspective.

One of the interesting business case elements in the Arnhem Nieuwe Haven case is the allocation of diesel fuel savings between competitors who make use of the same OPS cabinet. It was found that competitors are not willing to share savings with their competitors. To overcome this hurdle, the harbour master assigns the berth places according to organisation, avoiding that competing firms are connected to the same cabinet.

3.2.4 Opportunities to increase the use of OPS

Nijmegen estimated the utilisation of the OPS cabinets in 2017 for the river cruise ships at about 90% of the moorings. The remaining 10% that do not connect often have valid reasons (cables too short from assigned berth, short stay, cabinets fully occupied / use of Powerlock by other ships). The usage by the freight ships was estimated at about 20% of the moorings. The 20% utilisation rate of OPS for freight ships is in line with what had been reported for other Dutch ports.

There are few opportunities to increase the utilisation of OPS in Nijmegen, as already a high percentage of the river cruise ships connect to OPS. It has occasionally occurred that no electricity was consumed while ships were connected. In such cases the harbour master will talk to the skipper, or if that is not successful, could also contact the owner. The online platform offers the possibility to see which ships are connected and where. Enforcement is hardly necessary because using OPS is also in the shipping company's own interest: it gives the passengers a more pleasant stay on board (no noise and soot on deck). Besides aiming to increase utilisation of existing cabinets there are plans to add one extra OPS cabinet on the Waalkade.

In Arnhem the generator ban implemented per 1/1/2018 led to an increase in utilisation. Nijmegen implemented such a ban from the beginning.

An increase of the use of OPS for river cruise ships is in fact only possible when there is more "traffic" to the port (primarily an economic rationale) or when spatial/economic considerations lead to a different design of the quays. For example, cruise ships could be moored at the current designated spot for loading/unloading skippers' cars on the Waalkade, if an additional OPS cabinet were installed there. This cabinet can be positioned in such a way that today's problem of "too short cables" is also resolved.

There are only few opportunities to stimulate the use of OPS for the freight vessels. The number of moorings is very dependent on the economy. During loading or unloading of goods the ships are moored for too short time to use OPS, with the exception of container vessels. This is because ships want to leave as soon as possible to go to the next job. This is confirmed by the experience gained from earlier demonstration of mobile OPS in Nijmegen. The lesson learned is that the OPS will be used best if ships are at berth for longer time (for example if they wait for freight, or when they are staying in the Waalhaven), provided that the costs of OPS per kWh are not higher than when the onboard generators are used to generate electricity.

Specifically for Arnhem an opportunity to increase OPS usage is to combine services: new online services for skippers to increase the use of OPS in combination with payment of port fees or water intake.

From 2021 onwards the Dutch government decided that the energy tax on OPS is decreased to 0.05 eurocents per kWh and no additional 'renewable energy financing' levy is applicable. This reduces the cost of electricity purchases that could be passed on to skippers, improves the cost advantage of OPS compared to diesel and thus stimulates the usage of OPS.

3.3 Case Study: Container terminals Nijmegen and Doesburg

3.3.1 Policy background

In response to the subsidy scheme of the Arnhem Nijmegen City Region for investing in low-emission technologies for inland waterway transport, the privately held container terminals of BCTN and Royal Rotra applied for grants to install OPS on their quays for providing electricity to their own (chartered) container ships.

These companies have the ambition to decrease their CO_2 footprint and the burden on the environment (i.e. noise, air quality). BCTN aims to achieve zero emission terminal operations by 2030.

3.3.2 Implementation and usage

The total investment costs for four OPS connections for BCTN were € 45.000 for pulling cables over 40 to 320 meters from the existing transformer cabinet and installing four Mennekes five-pole 63A sockets. A 50% investment subsidy was granted by the City Region. For Royal Rotra the total investment costs were € 80.000 for hardware of the OPS cabinet, construction works, pulling cables and installation of electrical connections on the premises. In this case the City Region awarded 35% investment subsidy.

OPS sockets on BCTN and Rotra quays

The OPS has been operational with full satisfaction since 2017. Whereas BCTN does not charge for the use of OPS, Royal Rotra charges 27.45 eurocents (incl. VAT) per kWh to skippers. Rotra commissioned a service contract for administration, (dis)-connecting the meters, invoicing etc. to Involtum. Besides OPS for ships during loading and unloading, Royal Rotra also provides power for the cooling of reefer containers at the terminal.

3.3.3 Business case

BCTN's motivation for OPS on their terminal was that they normally pay the diesel for the ships they charter. The savings on diesel used by the on-board generators provide a solid business case. This is notable because, based on market consultations, there is hardly a business case for providing OPS during loading and unloading of freight vessels. Container terminals can be an interesting exception if the following conditions are in place:

- The costs and benefits of implementing and exploiting OPS are in one hand, and
- Time of loading/unloading is long enough.

BCTN reported savings of ca. 8-9 litres/hour of diesel for their chartered ships. There are also indirect benefits such as lower maintenance costs for the ship owners. The use of OPS is mandatory at the terminal if ships stay for loading or unloading longer than 3 hours, provided that connecting to OPS can be done safely.

The following business case for OPS use by a 208 TEU ship is illustrative:

A container ship arrives at BCTN four times a week and starts to unload for 6 hours and continues to load for 6 hours each time. The total berth time per visit is 12 hours. During this time, approximately 8-9 litres/hour diesel will be saved. If the average costs of diesel are 700 euro per tonne or app. 70 eurocents per litre, this will result in savings of app. € 10.000-15.000 per year (12 * 8 * 4 * 50 * 0,7 = € 13.440). Therefore the investments can be earned back in 3-4 years.

BCTN provides the electricity via a low-tension grid to the skippers for free and no service model (for administration, (dis)-connecting the meters, invoicing etc.) is applied so no other costs than management, maintenance, depreciation, and electricity purchase (with energy taxes) are involved. No specific numbers are available for the business case of Royal Rotra.

3.3.4 Opportunities to increase the use of OPS

BCTN installed OPS at their terminal in Alblasserdam (in the Rotterdam area) for four ships. They see opportunities for other inland container terminals (their own or by others) to install OPS if a user-friendly concept can be developed.

BCTN cannot provide electricity for the cooling of reefer containers during loading/unloading because the installed OPS connection has insufficient capacity, but this could be a viable business opportunity for others.

3.4 Case Study: Arnhem-Nijmegen OPS on private quays

3.4.1 Policy background

Besides stimulating OPS on public quays, the city of Nijmegen as part of the CLINSH project also facilitated the realisation of 5 OPS facilities on private quays in the *Kanaalhavens* in recent years. The Kanaalhavens are an important inland port and OPS was installed to improve air quality from operations and improve living conditions in nearby residential areas.

3.4.2 Implementation and usage

The city procured the installation of 5 OPS facilities, a total of 14 cabinets (varying 400V/32 Ampere and 230V/16A and 63Ampere). The actual usage is yet to be evaluated, however estimations were made for several facilities in the project proposals:

- EKI former paper mill: average yearly usage scenario: 50,000 kWh
- APN asphalt plant: during yearly maintenance period per year circa 5,000 kWh and in addition normal overnight charging (20 kW per night)
- Derks non-road and floating mobile machinery yard: it was estimated that a total of 100 ships would use OPS for a total of 4 – 8 hours per visit.

Illustrations OPS Cabinets in Kanaalhavens

OPS Cabinet Derks

OPS Cabinet EKI

OPS Cabinet APN

3.4.3 Business case

The investment costs for these OPS installations vary between approximately 100,000 euro at EKI and Derks and approximately 15,000 euro for the installation at the APN site. The large variation is because of the nature of the projects. EKI was a demonstration and pilot project in which different new OPS technologies were demonstrated and for Derks the costs also included the groundwork (2 locations) and replacement of a main distributor connection.

The procurement by the city of Nijmegen covered a large part of the investment costs for the OPS cabinets. Because data on actual usage is not yet available, it is not possible to draw conclusions on the business case for these companies.

3.4.4 Opportunities to increase the use of OPS

There are opportunities to realise more OPS in the Kanaalhavens, depending on the willingness of companies situated in the harbour. In light of the energy transition in Inland Waterway Transport it is foreseeable that OPS locations could be suitable as places where batteries could be swapped and the OPS infrastructure could be expanded and upgraded to charge batteries for ZE-ships.

3.5 Case Study: North Rhine-Westphalia

3.5.1 Introduction

North Rhine-Westphalia has a dense canal network with direct connections to the ports of the "North Range" which are the western seaports known as ZARA ports of Zeebrugge, Antwerp, Rotterdam, Amsterdam, and the German seaports. The canal system in NRW in the Rhine-Ruhr region with 5.3 million inhabitants has the most extensive network of inland ports in Germany. These inland ports are mainly used for cargo and freight shipping, serving the supply, import and export needs of the entire region.

Switching to Inland waterway transport relieves the burden on the surrounding rail and road infrastructure, reducing congestion, energy, and fuel costs. In terms of energy consumption per tonne of freight, inland shipping is already one of the most efficient means of transport. Nevertheless, work has to be done in Germany to shift to modern, energy-efficient and environmentally friendly vessels for inland waterways in order to achieve energy and cost savings as the volume of freight transported by inland waterways increases.

The advantages of inland waterway transport in comparison to road transport continue to stimulate a switch from conventional road transport to the modern inland waterway transport. These advantages are high transport capacity, lower energy consumption, lower personnel costs, reduced environmental impacts and safety. Inland waterways are an environmentally friendly alternative to trucks as a ship can replace up to 200 trucks. Per tonne/km, inland waterways produce significantly less carbon dioxide than trucks. But there are problems, inland waterways freight vessels often have old diesel engines that produce significantly more atmospheric pollutants than more modern engines. This is especially true for the emissions of nitrogen oxides (NOx) and particulate matter (PM10), which in the aged marine engines are now higher than those of road and rail.

Concerning possible measures to reduce emissions from the European barge fleet (about 14,000 vessels), much is to be done in comparison to the more advanced engine and exhaust gas technologies that are more common in road freight vehicles. Particulate matter, sulphur and nitrogen dioxides are causing higher levels of air pollution, especially in cities along the waterways. This is confirmed by the emission registry of the State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV NRW).

Ensuring good quality of the air we breathe is one of the essential foundations of human health. Therefore, in the "Directive on Ambient Air Quality and Cleaner Air for Europe" (2008/50/EC), the EU established limit values for particulate matter (PM_{10}: annual mean 40 µg/m³, maximum exceedance of 50 µg/m³ on 35 days/a) and nitrogen dioxide (NO_2: annual mean 40 µg/m³, maximum exceedance of 200 µg/m³ on 18 hours in a calendar year) that are binding for all Member States. For Germany, the directive was made binding by the

39th BImSchV (see CLINSH report (2021): B 4: Modelling, evaluating and scenario building: Harbour monitoring: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf).

With 18 million inhabitants, the federal state of NRW has the highest population of all German federal states. Around ten million inhabitants live in the Rhine-Ruhr metropolitan region, making it one of the most densely populated regions in Europe. In such densely populated metropolitan areas, the air is polluted by a variety of pollution sources (such as industry, domestic heating, road traffic, planes, etc.). There are eleven major cities in NRW directly on the Rhine with about 3.3 million inhabitants. The six largest cities on the Rhine are Cologne (1.1 million), Düsseldorf (0.6 million), Duisburg (0.5 million), Bonn (0.3 million) Krefeld (0.2 million) and Neuss (0,16 million). In these cities, the limit values of the EU Air Quality Directive for NO_2 could not be met for many years due to the high road traffic pollution, so that air pollution control plans had to be drawn up and updated. These plans also included root cause analyses and measures to reduce NO_2 pollution.
In these cities along the busy Rhine waterway, the diesel engines of inland navigation are also a significant source of emissions. The amount and effect of these emissions on air quality are also influenced by factors such as fleet composition and age of engines, traffic density, river morphology and location and equipment of berths.
In the discussion about suitable measures to reduce pollution, NO_x emissions from inland vessels have therefore also become the focus of public debate. One of the theses was that inland vessels could be one of the main causes of the limit value exceedances for NO_2 occurring in the conurbations. At first glance, this thesis did not seem implausible, since calculations with the "older" version of the state's own "Emissions register for inland shipping in NRW” (Emissionskataster für den Schiffsverkehr in NRW) showed high emission levels from inland vessels for the affected cities on the Rhine in the overall balance.
Even though the NO_2 pollution has decreased significantly in 2020 and the limit values were complied with for the first time at all official state measuring stations, the safe compliance with the annual mean value for NO_2 (40 µg/m³) is still a challenge in the urban agglomerations. For precautionary reasons, the pollution must be further reduced by suitable measures in order to ensure compliance with the limit values in the future. The question thus remains relevant.
The German inland waterway fleet has an average age of over 50 years, and the propulsion engines used are on average more than 30 years old. In the past, emission regulations for ship propulsion systems were less stringent than for trucks. More recent regulations, such as in the EU's NRMM (Non Road Mobile Machines) Directive 2016/1628, only apply to new ships or when the old engine on an older ship is replaced by a new engine. The older engines are grandfathered for the remaining period of use and therefore only have to comply with the emission regulations applicable in their year of construction. For many ship propulsion systems, therefore, no binding emission requirements apply at all. Therefore, significant reductions in ship emissions through routine fleet renewal are not to be expected in the short term for inland navigation.
Similar to vehicles in road and rail transport, inland vessels are also inspected for safety and functionality at regular intervals. Ship owners are free to choose in which EU Member State they want their vessels to be inspected. Within the framework of administrative assistance, LANUV NRW queried the data available in the German ZBBD database (German Ship Inspection Commission) on the engines and generators of the ships inspected by the Commission. The data used was mainly from German ships, but about 100 Dutch and

Belgian ships are also included. In total, data sets were available from 304 tanker vessels and 670 cargo motor vessels. For 291 tank motor ships and 622 cargo motor ships, information was available on the year of construction of the ship propulsion systems. The average age of the engines of the cargo ships was 37.5 years and for the tankers 22 years.

For a transit state like North-Rhine-Westphalia with a high population density the need to reduce CO_2 emissions and to improve the air quality especially in the cities along the waterways is crucial. Alternative propulsion solutions and cleaner fuels are necessary for more sustainable inland shipping as well as efficiency measurements such as the use of onshore power supply (OPS).

3.5.2 Ports of Duisburg and Neuss (RheinCargo)

By far the greatest concentration of inland ports in Germany, is found in NRW, with approximately 120 located in the state, 23 of which are public. These public ports handle approximately 125 million tons of goods pa. The port of Duisburg, Europe´s largest inland port, is also the most important inland port in NRW.

Company name: Duisburger Hafen AG	
Year of foundation:	**1926**
Size of workforce:	**approx. 1.500**
Annual turnover: (2019) 292,6 Mio euros	
Annual throughput:	**123,7 Mio t**
Industry:	**Logistics**

Duisburger Hafen AG is the owner and management company of the Port of Duisburg, with a total throughput of over 123.7 million tonnes and 4.0 million TEU (2019), the Port of Duisburg is the leading logistics hub for cargo handling in Central Europe.

Company name:	**RheinCargo GmbH**
Year of foundation:	**2003**
Size of workforce:	**approx. 650**
Annual throughput:	**(2019) 50 Mio. t**
Industry:	**Logistics**

On both sides of the river Rhine, RheinCargo GmbH & Co. KG runs the operational port and rail business.

RheinCargo is a joint venture between Neuss-Düsseldorfer Häfen GmbH & Co. KG and Häfen und Güterverkehr Köln AG. RheinCargo combines port logistics, rail freight transport and real estate leasing in six Rhine ports in Neuss, Düsseldorf and Cologne. On a port area of almost 700 hectares, the company handles around 50 million tonnes annually.

3.5.3 Policy background

Onshore power supply has been supported on the German national level and on an international scale by the European Union. Firstly, the federal government recognises that onshore power can be used a technical measure in improving efficiency in shipping, furthermore the federal government welcomes the funding of projects within the “Connecting Europe Facility” (CEF) framework in order to achieve a constant supply of onshore power. Secondly the European Union calls for the establishment of land-based power supplies in sea and inland ports by 31.12.2025 (based on Article 4 (5) Directive 2014/94/EU), provided there is a demonstration of demand, a positive cost-benefit ratio, and possible environmental benefits. The high investment costs for the installation of power distribution and connection facilities for ports and ships has led to stimulants such as the Electricity Tax Act (StromStG) which stipulates a reduced electricity tax rate of €20.50 per megawatt hour to be put in place. Furthermore, with the help of TEN-T funding, the attractiveness of onshore power can be increased in comparison to on-board power generation.

To meet the challenges facing German ports, the German cabinet released the National Port Concept in 2015. Some of the challenges that the concept aims to tackle are: cargo handling growth; tougher competition; stiffer demands on environmental protection and security. One of the key objectives of the National Port Concept is the strengthening of climate and environmental protection in ports, such as through the use of alternative fuels and onshore power supplies. Another aim of the federal government from the National Port Concept is to adapt the EU Energy Tax Directive to the point where a compulsory tax exemption exists for onshore power provided to commercial shipping. Lastly, the Federal Government is discussing further possibilities to support the supply of onshore power.

A problem which faces the supporters of onshore power is that the wide range of electrical power needed by ships, ranging from a few kilowatts to many megawatts, possibly requires new electricity generation and distribution facilities. To achieve this, considerable investments are being made to uprate distribution networks. This creates more favourable conditions for inland waterways to comply with emission and noise reduction requirements.

3.5.4 Funding possibilities

When seeking funding possibilities in NRW, the main focus must be towards the Leitmarktwettbewerb (lead market competitions). The State Agency for Environment NRW (LANUV) deals with the reduction of pollutions (mainly particulate matter and NOx). Other possible funding sources for onshore power projects are the German federal government and the European Union.

The German federal government and the state government of North Rhine-Westphalia has introduced directives and programs to fund onshore power projects, such as:

- BMVI Funding Directive Innovative Port Technologies (IHATEC) promotes technical innovations to increase energy efficiency in ports and reduce environmental pollution.
- The BMWi funding program "Innovative shipbuilding secures competitive jobs" supports innovations that achieve improvements in quality and performance in the environmental sector (e.g. optimisation of fuel consumption, engine emissions, waste and safety). This promotion can be applied to existing shipyards responsible for shipbuilding and ship repairs.Funding directive of onshore power supply systems for commercial inland shipping

(North Rhine-Westphalia). First-time construction and expansion of onshore power facilities at berths in North Rhine-Westphalia for cargo ships and commercially operated passenger ships in North Rhine-Westphalia that have been in operation for at least ten years. 80 % of the eligible expenditure for onshore power facilities for commercial inland navigation

- Max. 75,000 € for a single installation for the inland waterway transport
- Max. 350,000 € for a single installation for passenger navigation

- The federal government has also created a cooperative promotion to support up and coming engineers within the framework of "Research at Colleges".

The European Union has funding programs for onshore power projects; the first of these is the CEF program. For inland waterways, priority will be given to:

- Provision of alternate fuel infrastructure, such as LNG, Methanol, or electric charging.

For Inland ports, priority will be given to providing or improving:

- Introduction or implementation of fixed infrastructure regarding alternative energy, e.g. LNG bunkering and shore-side electricity.

The second program supporting onshore power projects is the Horizon 2020 program which states:

- MG-2.1-2017: Innovations for energy efficiency and emission control in waterborne transport
- Proposals should address one or several of the following aspects: Development, demonstration and evaluation of innovative pollution reduction and control technologies and modelling and simulation of solutions with full scale verification.
- MG-7-3-2017: The Port of the future.
- Research and innovation actions should address several of the following aspects:
  Low environmental impact, climate change adaptation and mitigation, and moves towards the circular economy.

For equipping and retrofitting sea-going and inland vessels with environmentally friendly on-board power supply systems:

- Eligible expenditure is defined as the difference between the investment expenditure incurred and that of a less environmentally friendly alternative. In cases where there is no less environmentally friendly alternative, the entire cost may be eligible.
- Funding earmarked for use in at least one German sea or inland port or at least one German berth and transhipment point.
- Funded equipment or conversions must be in use for five years after procurement.

For procurement of mobile shore power systems for shore supply to ships:

- Eligible expenditure: Additional investment expenditure for environmental protection

- The investment expenditure for the procurement of mobile shore-side electricity supply systems is calculated as a "separate investment" and corresponds to the additional investment expenditure due to environmental protection that is eligible for funding.
- Funding earmarked for use in German seaports or inland ports or at German berths and transhipment points. Must be in use for a period of five years after procurement.

State funding programme for OPS Programme

- Co-financing with funds from the Federal Government's Energy and Climate Fund
- Purpose: Construction and expansion of permanently operated and maintained shore-side power plants with electricity from renewable energy sources from additional generation
- Potential: 215 berths for cargo vessels and 90 berths for passenger ships
- Intended funding rate: 80%
- Start in 2021

3.5.5 Implementation and current use

In recent years , onshore power supply has been implemented in many ports in NRW, starting with the port of Cologne. At the end of 2015 eleven charging stations were set up in the “Rheinauhafen” for the supply of cargo ships. Since the spring of 2016, hotel and cruise ships can be supplied from three charging stations with onshore power at three piers of the “RheinCargo”, below the Düsseldorf Rhein terraces, as well as a station for leisure boats and houseboats was installed in the Düsseldorf Marina. In the Neuss-Düsseldorf port, a charging station for the connection of cargo ships has been installed. Finally, in the port of Duisburg, three smart charging stations were installed in spring 2019 for connection while the idle time in port.

Technical characteristics of the onshore power supply systems

Idle time for Inland Ships

Usually 85% of cargo ships on the Rhine have an average travel time of 14 – 18 hours, resulting in an idle time of 6-10 hours, for which onshore power supply is suitable. Trade fair and hotel ships can be alongside for much longer periods, making onshore power supply attractive.

A key difficulty is specifying the scale and capacity of onshore power supply (OPS) facilities. RheinEnergie have specified the power needs for their OPS units based on their own measurements (initially they thought that 50 kW would be sufficient but the measurements showed otherwise):

- Hibernating medium-sized river cruise vessel: 78 kW
- Hibernating river cruise vessel: 125 kW
- River cruise vessels with full hotel function: 300 kW.

The figure below shows the situation. One (initially rented) transformer with one (self-developed) OPS cabinet (with Powerlock) has been installed for 10 ships; three more similar installations are planned, making a total installed power capacity of 3 MW. This is sufficient for 34 vessels including 3 that provide hotel facilities. The maximum average total power required for 10 ships has been measured at 1,748 kW (real-time monitoring), but there are peaks especially when air-condition compressors are running.

Port of Cologne, OPS for Viking Company river cruises

Summary of results

- The establishment of a nationwide network of charging stations incurs high investment costs, economic support measures are needed to be financially viable.
- Due to high diesel prices, onshore power supply can help reduce fuel costs.
- Port operators and investors are interested in mobile onshore power solutions since these can ensure a demand-driven and flexible use of onshore power. This solution is also feasible for terminals.

Onshore power supply stations in Germany – NRW

In Germany there is a wide, but non-uniform network of onshore power facilities.

- The majority of the OPS facilities in Germany are operated by the Federal Waterways and Shipping Administration (WSV). These differ in their power capacity as well as in the design of payment systems.
- On the busy Rhine and Wesel-Datteln canals, on the Dortmund-Ems canal and on the coastal canal, a current of 16 or 32 amps is available at a voltage of 400 V. The North German inland waterways, the Mittelland canal and the Elbe side canal are mainly providing ships with 16 amps and 230 or 400 volts.
- A similar range of different systems can be found at the OPS stations in German inland ports.
- The CEE plug is the standard throughout Germany.
- Another project which organizes Onshore Power Supply (OPS) is the TankE-project for electric charging of vehicles with the brand name 'Schiffs-TankE'**.** River cruisers can reserve and start OPS under the same app as electric vehicle users; OPS for freight vessels is reserved and started by SMS text message.

Use of OPS: Experiences and usage of the project "Schiffs-TankE"

RheinWerke GmbH is a joint venture between the two energy companies: RheinEnergie AG and Stadtwerke Düsseldorf AG.

Creation of a demand-oriented infrastructure:

- Both companies build in Düsseldorf and Cologne, the infrastructure for e-mobility
- experience in the field of onshore power supply available
- Contribution to the design of charging stations, security technology, accounting systems, etc.
- Create a 24/7 control centre for network monitoring and customer service
- Participation in projects/tender for the development of the e-mobility infrastructure

The main reasons for the RheinWerke GmbH to establish OPS infrastructure are:

- Meeting targets from cities and municipalities to reduce particulate matter and CO_2
- Generators can be switched off by supplying power from shore
- Shore power includes the power cabinet, installation, software, power supply and billing.
- Connection to the local power supply must be ensured.
- Charging of batteries for future electrified inland waterway vessels

The OPS systems needed vary depending on the ships to be supplied with power. Mostly, there are 3 types of ships, with different use profiles and hence different requirements for OPS systems:

- River Cruise Vessels
  - Swimming pools
  - Hotel infrastructure must be supplied
  - High electricity demand during idle periods
  - Cabins also need electricity (air conditioning, TV, refrigerator etc.).
  - Flexible waiting times
  - Only a few customers, each operating a fleet of ships
  - Requirement >400 A
- River cargo vessels
  - Lower power consumption
  - Limited waiting periods only to comply with statutory rest periods
  - Power consumers on the ship are kitchen appliances, lighting, TV, etc.
  - Comparable to a single-family house
  - Requirement <125 A
- Recreational vessels
  - Very low power consumption
  - Irregular operating behaviour
  - Large number of different customers
  - Supply from the on-board power supply only relevant in the summer months
  - Duration of time berthed alongside is variable
  - Demand <32 A

The different use profiles and ship types result in different hardware requirements for OPS systems:

<u>Passenger cabin ships:</u>

- Shore power station meter cabinet
- Different connections for different currents
- Equipped with GSM modems for communication with software
- Powerlock connections
  - For current between 125 A and 400 A
  - 5 individual plugs and socket-outlets, mechanically coded
  - Default: 2 x 400 A Connections
- CEE-Connections
  - For currents up to 125 A
  - 5 pole connector
  - Default: 1 x 63 A and 1 x 125 A

<u>Freight and recreational shipping</u>

- Shore power column and meter cabinet in one
- Upper area for connecting the ships to the column
- Lower area without access for customers and for maintenance only
- Equipped with GSM modems for communication with software
- Stainless steel design for improved aesthetics and robustness
- CEE-Connections
  - For currents up to 125 A
  - 5 pole connector
  - Default: 1 x 16A, 1 x 32A and 1 x 63A

GWDS

As of August 2020, according to the General Directorate for Waterways and Shipping (GDWS), a total of 120 new OPS stations have been built at 20 different points along the four canals: Wesel-Datteln-Canal, Rhine-Herne-Canal, Datteln-Hamm-Canal and Dortmund-Ems-Canal.   At the stations it is possible to charge with 16, 32 or 63 amperes. With a power capacity of 40 kW, the stations cover all oil and bulk carriers. Payment arrangements have been improved, customers only need an RFID card to take power, which allows them to identify themselves by holding it in front of the OPS station's sensor field.

Situation in other NRW ports

There are many other ports in NRW where onshore power is not yet widely used, these ports are both publicly and privately owned.
For the biggest port in NRW, located in Duisburg, the following facts are relevant:

- Large port (12,000 freight ships, 170 idle passenger ships p.a.)
- Shared property, owned by public and private sectors
- Onshore power connections for 4 ships (380 and 400 volts)
- Operator: Port of Duisburg AG
- Billing on tokens (to be bought from the harbour master)

- Investment costs for a completely new onshore power facility starting from €30,000
- Planning OPS on Mercator Island, for river cruise ships
- The industry is reluctant to use OPS for reasons of cost, no uniform billing systems, and handling.

OPS for hotel and cruise ships

In the north of the “Oberkassel bridge” in Düsseldorf, two piers were equipped with power connections for ships in 2017/18.

On the banks of the river Rhine in the Düsseldorfer district of the old town - especially at the time of trade fairs - hotel and cruise ships are berthed. To maintain the power supply on the ships, the diesel engines of the ships run during the berthing times. This causes considerable emissions of particulate matter, CO_2, and noise, which can be avoided if the ships are supplied with electricity from onshore power.

3.5.6 Business case

Investment

The costs for the entire installation of 4 OPS stations to deliver 3 MW of electricity for 34 vessels in the port of Cologne are estimated to have been below €1 million. A major part of the cost was groundworks for cables. The fact that the generation plant is adjacent avoids the need for expensive grid reinforcements, but it was not a reason to choose this location.

The cost for OPS in Cologne is 26 cts/kWh including VAT, but 2 cts energy tax can be reclaimed from the tax office. The amount of energy consumed at this location is not enough to qualify for the cheaper rate for major consumers. In Duisburg for example the price per kWh (ex VAT) is 18 cents.

The payback time for the Cologne port project is assumed to be between 7 and 10 years. Currently there is no further information in regards to the business cases for the OPs at other ports.

Societal and environmental benefits

Onshore power is an option to reduce emissions from ships while in the port. The extent of the reduction depends mainly on the type of fuel burned in the ship and the energy mix used for the electricity generation onshore. Onshore power supply, fed by a conventional energy mix, has no or only minor ecological advantages compared to the electricity generated on board. This ratio can change as a result of the increasing generation of electricity from renewable energy sources. In any case, OPS stations help minimise external noise and exhaust emissions in populated areas and reduce the noise levels experienced by crew members and adjacent vessels during rest periods.

Summary conclusions

1. Onshore power supply is most suitable for river, hotel, and accommodation ships, this is due to the longer time these ships are at berth.
2. Mobile onshore power solution for ports may be more attractive than fixed OPS due to the extra flexibility in the mobile stations.

3. There will be a tendering process carried out by the WSV for OPS in ports of greatest need of the technology.
4. Port services and costs are known for some ports.

Further actions required

Due to the wide range of possibilities to further develop and enhance onshore power supply, certain measures and tasks can be taken such as:

1. Onshore power is currently only for river, hotel, and accommodation ships, therefore possibly an expansion of the onshore power facilities from ports to docks can be carried out to expand the reach of onshore power supply.
2. Further researching of services and costs for some ports.
3. Funding program can be initiated for the ports that have concerns in regards to building OPS facilities.
4. It would be possible to investigate mobile land-based OPS more closely and see whether the ports would have a higher acceptance for these than for fixed land-based onshore power plants.
5. The legal framework for the construction and use of OPS can also be looked at in more detail.
6. In NRW a uniform use of the shore power plants can be made possible through standardized payment methods.

3.6 OPS energy-scan

A programme of 26 energy and shore power scans of inland ships, were performed in the first half of 2021, covering the Port of Antwerp, North Sea Port, De Vlaamse Waterweg and Mow Vlaanderen. The work was conducted by ENPROVE BVBA on behalf of the CLINSH project.

Summary – (full report available separately)

OPS Cabinet Antwerp

- About 31% of the ships in this study experience technical problems when connecting to shore power.
- When the ship is conform NEN-EN 15869-3:2019 standard, no problems with using shore power are identified. This makes the standard a good tool for making ships electro technically compatible with shore power.
- Only 31% of the ships in this study are conform NEN-EN 15869-3:2019. The most common technical infringements are: (i) no isolation transformer (54% of the ships), (ii) no IP67 shore power cable/plug (42% of the ships), and (iii) no soft start switch (peak current) (15% of the ships). Mostly this doesn't mean the ship can't use shore power.
- The most common reasons why skippers don't use (often) shore power are: (i) not enough shore power cabinets (54%), (ii) the price is too high (50%), (iii) no good accessibility of the cabinets (31%), (IV) technical issues on board (31%), and (V) not sufficient power (23%).
- The average electrical power consumption of the inland vessels in this study amounts 6.33 kW. This is also the mean power consumption when berthed (e.g., when using shore power).
- The average fuel cost (incl. maintenance) for generator power of all ships included in this study amounts 0.25 €/kWh. This is lower, but comparable to the standardized shore power price (0.27 €/kWh).
- When energy-saving measurements are implemented (excluding maximizing shore power use), the average load of the generator set decreases, which increases the cost of generator power. Thus, favouring the use of shore power.
- When all profitable energy saving measurements (payback time < 4 years) identified in the energy scans are implemented, the average primary energy savings per ship (only taking into account the electrical consumption on the ship) for different ship types amounts, 30% for a passenger ship, 48% for a tanker, 27% for a container ship and 19% for a dry cargo vessel.
- The most common energy saving measurements with the highest energy saving potential for the lowest investment cost are: (i) adjusting sanitary boiler control, (ii) limiting the use of electrical resistance heating, (iii) maximizing shore power use, (IV) replacing the lighting with LED, (V) residual heat recovery engines, and (VI) energy monitoring.
- The total savings of all cost-effective measures (< 4 years) identified during these 26 energy scans amounts 1,935,144 kWh/year primary energy and 499 ton CO_2-eq/year.

4 Barriers to Further Deployment

4.1 Barriers in terms of Standards and Regulations

In recent years, considerable progress has been made to promote onshore power supply, but there remain a number of aspects where further developments are needed, such as standardisation of electricity parameters, uniform physical and operational system, lack of international and European regulations, lack of financial support, communication and awareness about the environmental benefits of OPS….

A barrier to further deployment of OPS is represented by some technical problems concerning lack of standardisation. This concerns compatibility of electricity parameters: ships, built in different international yards, have no uniform voltage and frequency requirements. The European Commission made some progress in the standardisation of OPS for inland shipping (Delegated Regulation (EU) 2019/1745 of 13 August 2019 that include the shoreside electricity supply for inland waterway vessels). However still more attention is paid to the standardisation of OPS for maritime shipping than for inland navigation.

Convenience of the physical and operational system is also important. Different management systems (registration, reservation of an OPS connection point, starting electricity provision and payment) does not encourage potentially users. Cashless settlement for the electricity used should be possible everywhere. Ideally in combination with a standard Europe-wide payment system.

Due to the high investment costs, not enough OPS locations and not enough connection points per location are available. The OPS users claim that more berths and more OPS connections points are needed at one location, especially when ships are side-by-side making the connection to OPS difficult and sometimes for safety reasons not allowed.

EU ports are in the focus of EC regulations to deploy OPS, which results mainly in high needs for port investments. However not enough financial instruments have been deployed. Lack of financial support is really one of the major barriers to further deployment of OPS. When taking into account strictly the return in terms of cash flows, it appears that OPS is not really justifiable from a financial perspective. To make the desired OPS investments possible, grants from the EC or from national programmes are necessary and/or existing financial reserves will have to be addressed. Policy makers should give more visibility and opportunity to OPS in their financial programmes.

The cost of electrical energy represents a major barrier to the adoption of OPS in Europe. The important barrier to investment in OPS is that taxes are imposed on OPS, but not on fuels used in shipping. There is a disruption in the level playing field between shore side electricity and on-board energy production since this is only subject to limited taxation. Ports authorities and skippers are in favour of the electricity taxation exemption for OPS. This issue is being considered for the amended Energy Taxation Directive, (Fit for 55).

The sector is resistant to any obligation to use onshore power or a possible generator ban, which is the case in several ports already. A culture change amongst skippers is needed to comply with the generator ban without making enforcement of the ban an onerous task for the ports. Therefore communication and awareness about the environmental benefits of OPS is crucial.

4.2 Barriers in terms of Economics

As mentioned above, at the present time, there are two significant economic barriers to increased deployment of OPS facilities and their usage by vessel operators:

- The cost per kWh of electricity generated by an on-board generator is much lower than the cost of electricity imported to the vessel via OPS. Changing this will require regulatory measures that internalise societal costs (e.g. from poor air quality) into energy prices.
- Provision of OPS facilities involves significant capital expenditure by ports, and also by vessel owners to connect to OPS. In purely economic terms, the investment case is very weak. The vessel owner is expected to invest in equipment that delivers a negative return (i.e. increases their operating costs). The risk that vessel owners will be unwilling to make use of available OPS facilities also undermines the port's case for investment in providing those facilities. This behaviour has been observed (at North Sea Port) where vessels connect to OPS but do not draw any electricity from it: they choose to run their on-board generators instead.

4.3 Barriers in terms of Politics

The economic barriers can only be resolved with political commitment to address air quality concerns. The societal costs of poor air quality are substantial and well-known. If those costs are to be transferred onto the industrial and commercial sectors that contribute to air pollution, then regulation and/or financial instruments are necessary.

As mentioned above, such measures are never popular with the sectors affected, yet clean air zones and other restrictive policies are in place in many cities. Scrappage schemes have also been deployed (for road transport) to remove the most polluting vehicles from the fleet. These kinds of instrument can be successfully applied to waterborne emissions in cities, provided they are well-designed and targeted.

Within CLINSH, scenarios have been identified that would enable significant reductions in emissions from vessels at berth. These are presented in the following chapter. The policies needed to realise these scenarios could offer vessel owners various options for reducing their emissions, including greater use of OPS. Political leadership will, however, be needed to implement such policies.

Absence of political leadership is likely to mean that Business As Usual continues into the future.

5 Scenarios of future OPS deployment

This section considers the policy and other measures that could mobilise future deployment of OPS. Such deployment does, of course, depend on the availability of harmonised OPS installations that offer the required inter-operability, as presented in previous sections. However, increased deployment is unlikely to happen without a policy intervention. The cost implications of such policy have to be weighed against the resulting environmental benefits that would be anticipated.

5.1 The Scenarios Context

In the context of aggregated annual emissions from inland vessels, the contribution of emissions from vessels at berth is very small in comparison with the emissions produced from vessels underway. Policies that influence emissions reduction from vessel propulsion will dominate the factors motivating policy-makers in this domain. Some of these policies (eg engine emissions standards, fuel levies, emissions taxes etc) are likely to affect OPS use as well, although OPS-specific policies are also possible.

It is important to ensure some consistency between OPS policies and the wider fleet policies. Within CLINSH, fleet policy scenarios have been focused down onto two cases: 1) BAU and 2) the CLINSH scenario. The latter assumes that in any year until 2035 the fleet is renewed with 1) Stage V for ships whose engines are up for revision/re-engining, 2) a limited number of zero emission technologies and 3) accelerated introduction of CLINSH technologies ahead of revision schedule. After 2035 it is assumed that zero-emission options become mainstream and skippers/owners choose zero emission by default.

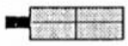
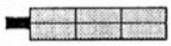
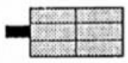
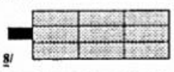
It was decided, therefore, to frame any OPS-specific policies under the heading of reduced-emission options consistent with the CLINSH fleet scenario above. An important consideration is the likely difference in emissions at berth under these OPS-specific policy options and the BAU scenario.

5.2 The Emissions Context

In the first instance, it is necessary to estimate the relative importance of different sources of emissions from vessels at berth. To do this, the emissions from a notional fleet of 50 vessels of each category has been estimated. Four different categories have been considered:

- Cargo vessels that require power for the bridge and crew accommodation;
- Tanker vessels that require additional power for pumping, especially for unloading operations that use on-board pumps;
- Cabin vessels or river cruisers that require significant power for hotel load;
- Vessels that require heating of crew accommodation in winter.

The first three categories map onto the CEMT classes which are outlined in the figure below. Requirements for vessel heating are not restricted to any particular vessel class.

Classes of navigable waterways	Motor vessels and barges					Pushed convoys				
	Type of vessel: General characteristics					Type of convoy: General characteristics				
	Designation	Maximum length	Maximum beam	Draught 7/	Tonnage		Length	Beam	Draught 7/	Tonnage
		L(m)	B(m)	d(m)	T(t)		L(m)	B(m)	d(m)	T(t)
2	3	4	5	6	7	8	9	10	11	12
I	Barge	38.5	5.05	1.80-2.20	250-400					
II	Kampine-Barge	50-55	6.6	2.50	400-650					
III	Gustav Koenigs	67-80	8.2	2.50	650-1,000					
I	Gross Finow	41	4.7	1.40	180					
II	BM-500	57	7.5-9.0	1.60	500-630					
III	6/	67-70	8.2-9.0	1.60-2.00	470-700					
IV	Johann Welker	80-85	9.5	2.50	1,000-1,500					
Va	Large Rhine vessels	95-110	11.4	2.50-2.80	1,500-3,000					
Vb							172-185 1/	11.4	2.50-4.50	3,200-6,000
VIa							95-110 1/	22.8	2.50-4.50	3,200-6,000
VIb	3/	140	15.0	3.90			185-195 1/	22.8	2.50-4.50	6,400-12,000
VIc						 	270-280 1/ 195-200 1/	22.8 33.0-34.2 1/	2.50-4.50 2.50-4.50	9,600-18,000 9,600-18,000
VII						 8/	285	33.0-34.2 1/	2.50-4.50	14,500-27,000

Traditionally, fossil fuels are used to meet these energy-consuming functions, either from an auxiliary diesel-electric generator or from an oil-burning boiler as used in domestic heating systems. An OPS solution would aim to displace these fossil fuel consumptions with an electric power supply. The emissions reduction offered by OPS has been roughly estimated below.

5.2.1 Cargo vessels

For context, the likely scale of emissions from 50 freight vessels at berth is estimated. A daily emission quantity of 17.5 kg NO_X would be expected, which would add up to a quantity of 6,400 kg over the year. For PM, 600 g daily and an annual quantity of 216 kg would be expected, consisting almost entirely of soot.

5.2.2 Tanker vessels

For 50 tankers at berth without shipboard loading activities, higher emissions result from the higher energy demand despite younger, i.e. "cleaner" generator equipment. For NO_X the expected emissions are 36.2 kg/d daily equivalent to 13,200 kg annually. For PM, the emissions are 2.7 kg/d equivalent to 973 kg annually.

Vessels using shipboard pumps for unloading will impose much higher emissions. Thus it appears that emissions from a typical tanker vessel are significantly higher than those from a typical cargo vessel.

5.2.3 Cabin and cruise vessels

The majority of emissions from this type of vessel are coming from river cruisers in the range 86-110m; there are many of them, and almost half are more than 20 years old which means that their auxiliary engines have poor emissions characteristics. In contrast, the larger vessels (up to 135m) are relatively new.

Although it is unrealistic to imagine 50 river cruisers at berth at any time, by way of comparison such vessel numbers would emit over 500 kg of NOx and nearly 20 kg of PM per day (assuming half are 110m and half 135m). This equates to nearly 200 T per annum NOx and 7 T per annum PM, using the emissions data from LANUV[7].

Fortunately such vessels are strongly motivated to use OPS where available, as passengers are inconvenienced by the noise and pollution from running generators at berth. So in reality, the level of emissions from this type of vessel is much lower, at least in locations where OPS is available.

5.2.4 Heating in Winter

Vessels having a requirement for heating of crew accommodation in winter, while the vessel is at berth without main engines running, generally use a domestic oil boiler which is designed for a similar heat output. LANUV has performed an approximate calculation of the emissions resulting from these devices.

For a heating system with nominal heat output 37 kW (eg Max Prüss vessel), the following emissions per full load hour are determined:

- NO_X : 5.6 g/h
- PM_{10} : 0.12 g/h

In estimating the emission quantities, it is assumed that these plants are operated at full load for 980h per year. This results in an annual average operating time of about 11.2% of the annual hours, which corresponds to a running time of about 6.5 minutes/hour.

For 50 such vessels in the port at any time, LANUV calculates a worst-case annual emissions loading of:

- NOX : 269.8 kg/annum
- PM_{10} : 5.8 kg/annum

These figures are considerably lower than those resulting from on-board generators, so the effect of vessel heating on overall emissions will not be taken further within the CLINSH OPS work. Furthermore, it is unlikely that OPS would be economic to use for vessel heating.

[7] CLINSH Deliverable: B.4 Modelling, evaluating and scenario building: Harbour monitoring, Part B: Determination of NOX and particulate matter emissions from inland vessels at berth LANUV NRW

5.3 Estimating BAU emissions at berth

A methodology has been developed to allow the business as usual (BAU) emissions to be estimated, and thereby to estimate the benefit offered by OPS deployment and use.

Other CLINSH actions have identified the lack of robust data on emissions at berth with a resulting high uncertainty in estimated emission levels at a specific port. Nonetheless, a methodology is required for estimating the emissions resulting from the different categories of vessels operating in a specific port, since this will determine the scale of emissions reduction that could be achieved by use of OPS. This methodology comprises the following steps:

1. Quantify the number of vessel visits to the port in question, using AIS data collected in CLINSH, sub-divided into the CEMT vessel classes;
2. Analyse the average duration of berth visits according to CEMT vessel classes. Apply this to the annual number of vessel visits (from step 1) to calculate total annual hours at berth, for each vessel class, at the port in question;
3. For each CEMT vessel class, apply an auxiliary engine age profile based on CLINSH survey data to estimate the engine emission standard that is likely to apply to the auxiliary engines on each vessel class.
4. Based on the results from step 3, assign the typical emissions characteristics of the auxiliary engines installed on each vessel class, based on the TREMOD engine data. This allows the at-berth emissions per hour produced by a vessel in each CEMT vessel class to be estimated;
5. Calculate the annual at-berth emissions per vessel class at the port in question, by multiplying the emissions per hour (step 4) by the annual hours at berth (step 2). Sum the emissions across all CEMT vessel classes to give the total annual at-berth emissions at the port in question.

This is a simplified methodology that can be applied by any port, simply using the AIS records of visiting vessels which are readily available. There are several important assumptions and simplifications underlying this method which need to be stated:

- AIS data does not distinguish whether tanker vessels are loading or unloading when they are at berth. Emissions are much higher for an unloading vessel that uses its on-board generator to drive the discharging pumps. Ports can estimate the proportion of loading vs unloading operations based on their typical activities;
- Discrepancies between the AIS berth data and the berth data gathered from port records, at least for the port of Duisburg. It is not clear if this issue is a feature of the Duisburg traffic (eg some stationary vessels are detected by AIS as being berthed when they are actually moored in the channel). AIS berth data should be validated against port visit data wherever possible;
- The age and emissions standard for on-board generators is sometimes not known by the operator, and the CLINSH data is based on a limited (German) survey sample. Additional survey data across the fleets operating in other countries would enhance the accuracy of this data;
- The hours at berth for a visiting vessel of a given class is likely to vary depending on the specific loading or unloading facilities available and operational requirements. Use of an average figure across all ports is therefore a simplification, and more accurate port-specific data would enhance accuracy;
- The model assumes emissions for all the hours that a vessel is at berth, but some vessels may not be running their on-board systems for all the hours when they are at berth. For example, a

river cruiser may switch off its HVAC if it is alongside for some hours before accepting passengers.

The model presented in this guide therefore allows a port to create an initial estimate of at-berth emissions using readily available data. This is useful to determine the significance of at-berth emissions, and the rationale for reducing them by deploying OPS. Case studies of the methodology for four ports are given in the Annex to this guide.

Some ports may subsequently choose to refine the simplified model by applying port-specific data that they can collect. This has been done by the port of Duisburg, as presented in the CLINSH report "Harbour monitoring, Part B: Determination of NOX and particulate matter emissions from inland vessels at berth" (Action B4).

5.4 Reducing BAU Emissions at berth by deploying OPS

Three principal scenarios have been studied in order to assess the impact of different emissions reduction measures, including wider deployment of OPS. The at-berth emissions analysis (see Annex) showed that the relatively small number of vessels having old auxiliary engines (pre-dating emissions standards) contribute a disproportionate amount of pollution. Therefore it makes sense to focus one emission reduction scenario on measures to remove those auxiliary engines from operation at berth. This could be achieved by:

- Scrapping these old engines and replacing them with new engines that meet Stage V emissions standards or equivalent;
- Prohibiting vessel owners from running these old engines at berth, which effectively obliges them to use OPS instead. This is likely to be politically more attractive since it gives vessel owners a choice between OPS and engine replacement.

In order to reduce at-berth emissions further, additional measures would be needed to prevent use of auxiliary engines at berth. Since the largest vessels with large at-berth loads (ie tankers and cruisers) tend to be responsible for large individual contributions to emissions, measures that target such vessels are likely to achieve a useful reduction in emissions.

This gives the following three scenarios for analysis and comparison:

BAU Scenario	All vessels use their existing auxiliary generators while at berth
Age Restriction Scenario	As BAU except that on-board auxiliary generators older than 20 years are prohibited from operation at berth
Age & Size Restriction Scenario	As for age restriction scenario with the addition that the larger vessels (tankers > 68m and cruisers > 85m) are mandated to use OPS instead of their on-board generators

5.5 Estimating the impact of OPS policy measures on local air quality

Although the aggregated emissions from inland waterways are dominated by those from propulsion, nonetheless within port cities the vessel emissions at berth may be significant causes of localised air quality reduction and noise nuisance. Propulsion emissions are distributed along the length of the waterway, where they are dispersed and diluted over a large area. In contrast, at-berth emissions are concentrated at one point, often in a centre of population.

In order to investigate the possible effects of OPS on local air quality, the emissions figures provided above have been analysed using the dispersion models run by DCMR.

5.5.1 Nijmegen Air Quality Improvement

The initial analysis by DCMR has modelled the reduction in pollutant concentration in the vicinity of the port as a result of implementing one of the above policy scenarios, compared with the BAU scenario. Under the BAU scenario, the worst-case emissions from vessels at berth in Nijmegen were calculated as:

- NOx = 14,572 kg/year
- PM = 664 kg/year

Under the 'Age Restriction' scenario, the emissions were calculated as:

- NOx = 7,086 kg/year
- PM = 181 kg/year,

Giving an emissions reduction of:

- NOx = 7,486 kg/year (50%)
- PM = 483 kg/year (73%)

This reduction was assumed to have been achieved at the known berth locations used by the majority of each vessel type. The dispersion model then calculates the resulting reduction in airborne pollution in the areas surrounding the port.

Similarly, under the 'Age + Size Restriction' scenario, the emissions were calculated as:

- NOx = 3,113 kg/year
- PM = 86 kg/year

Giving an emissions reduction of:

- NOx = 10,873 kg/year (78%)
- PM = 1,091 kg/year (87%)

The results in terms of improvement in pollution concentrations are plotted on the figures below.

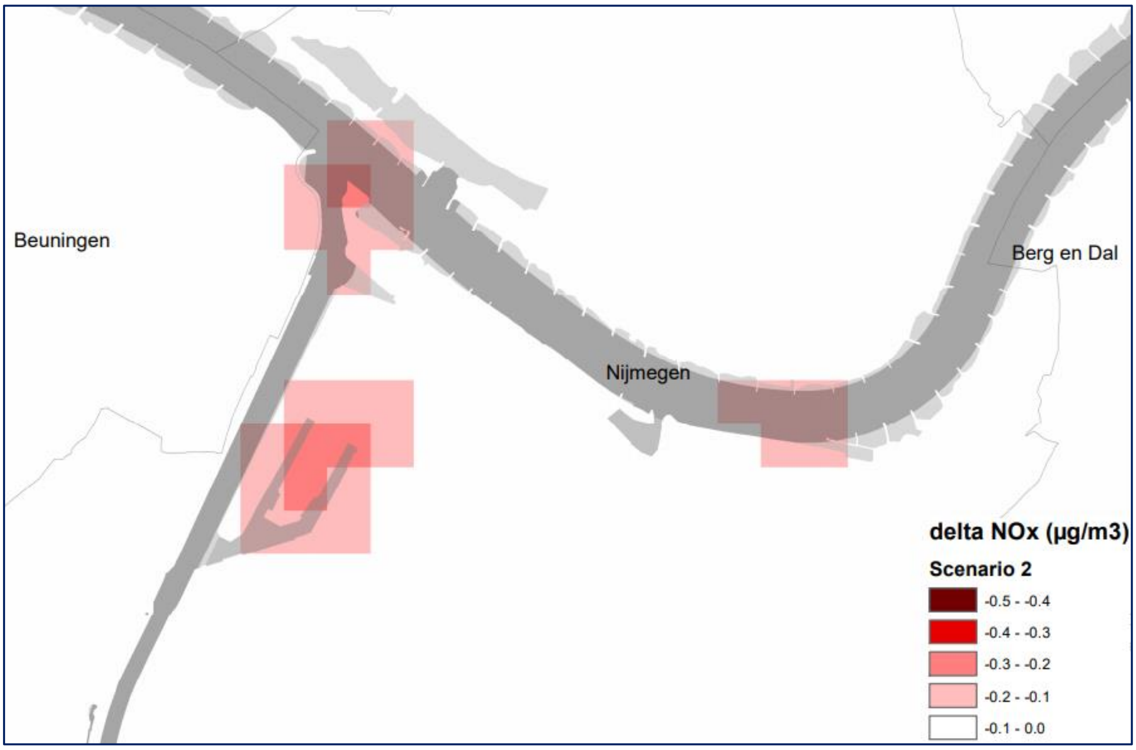


Figure 1 - Air quality (NOx) improvement under 'Age Restriction' scenario

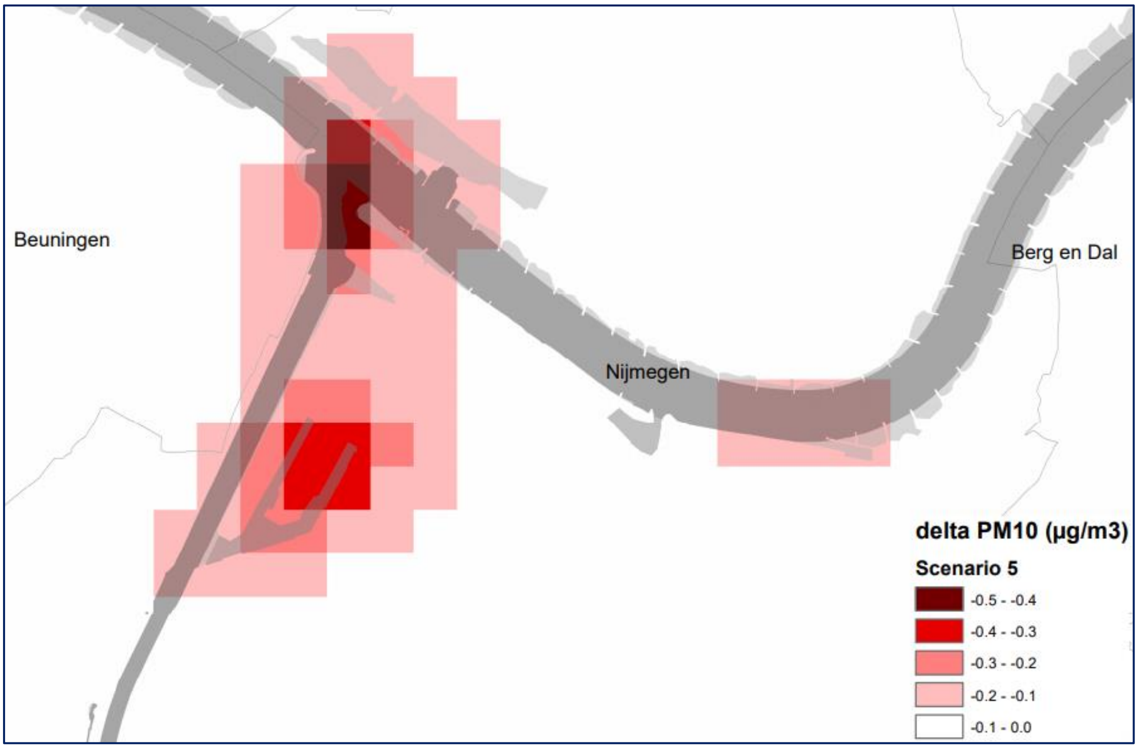


Figure 2 - Air quality (NOx) improvement under 'Age + Size Restriction' scenario

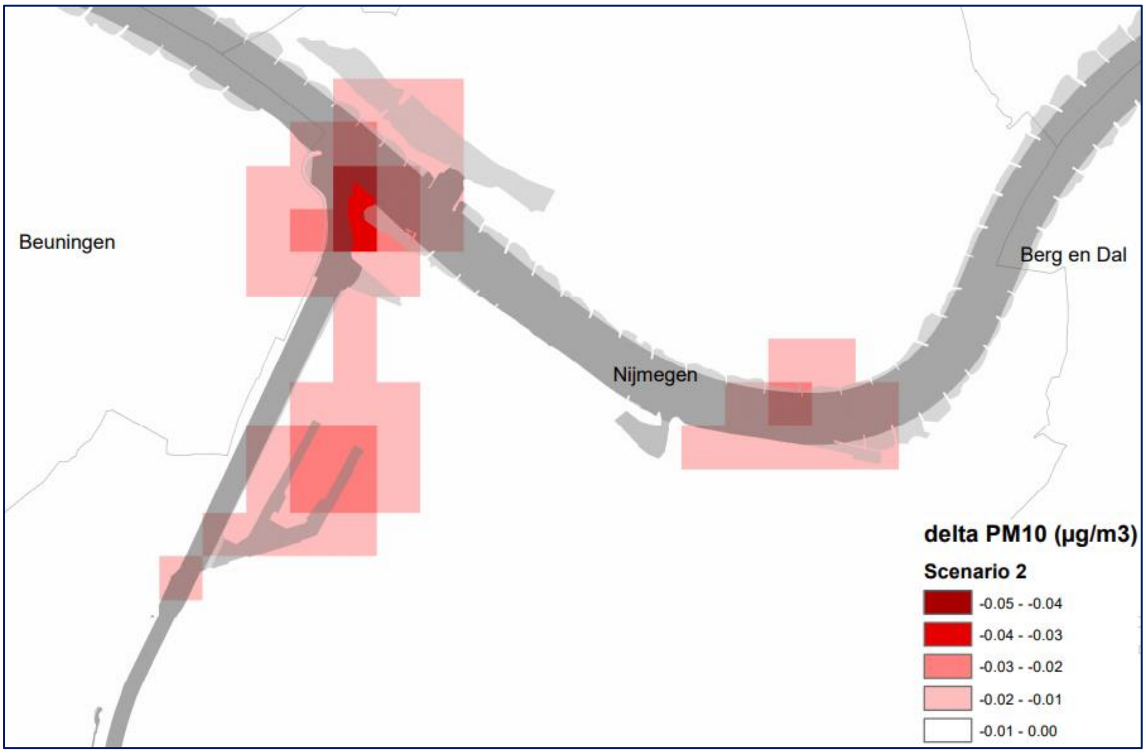


Figure 3 - Air quality (PM) improvement under 'Age Restriction' scenario

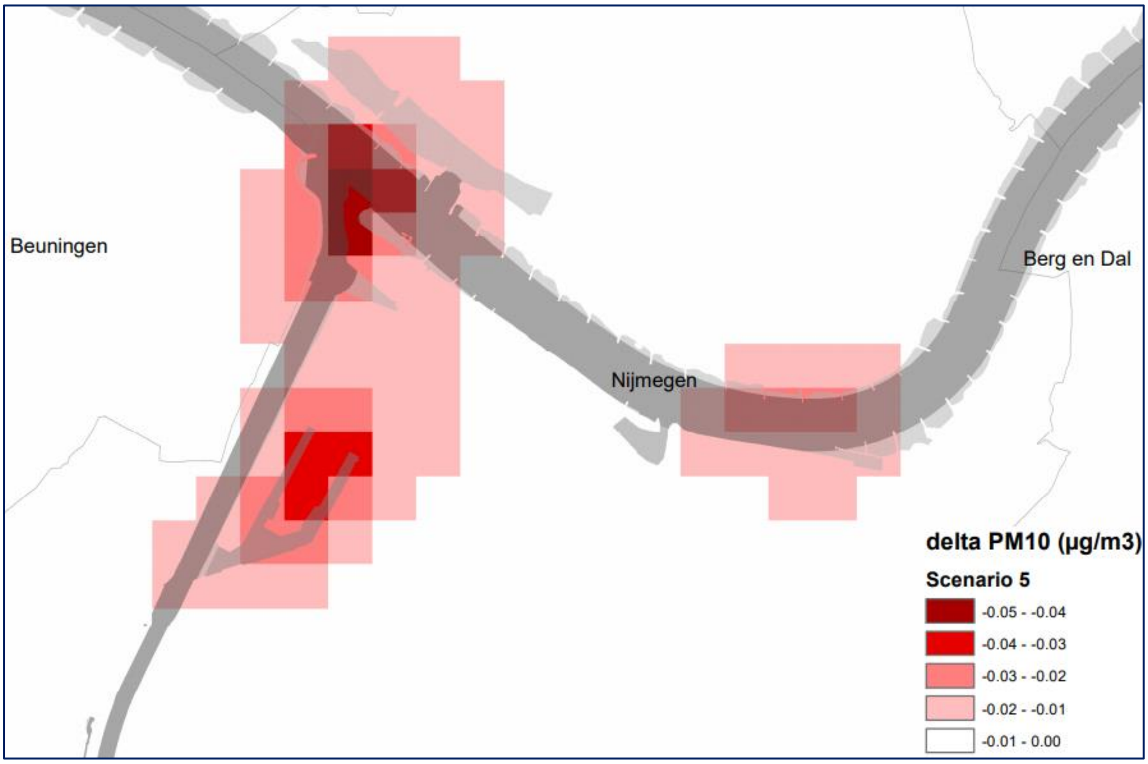
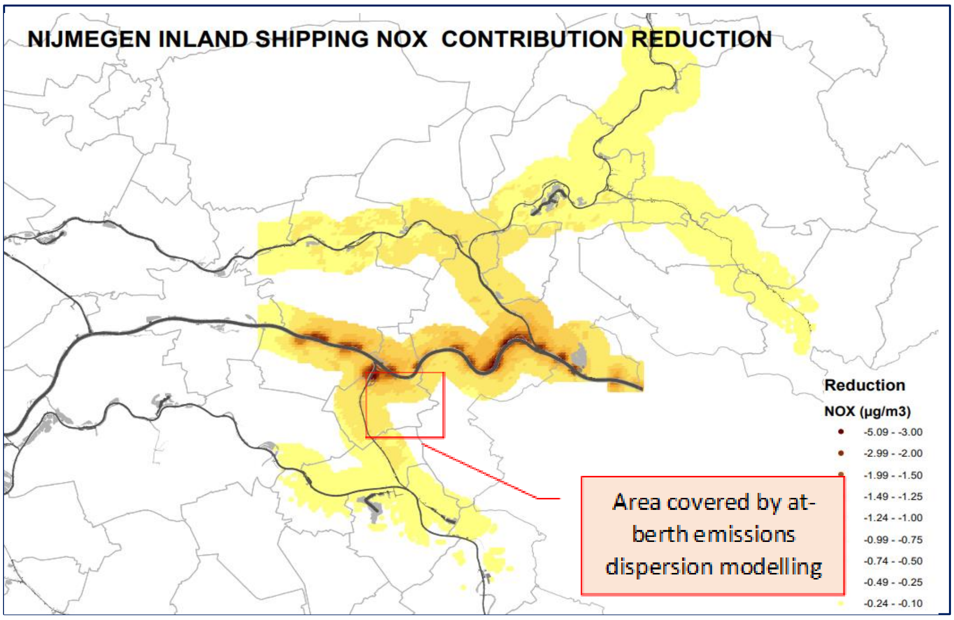


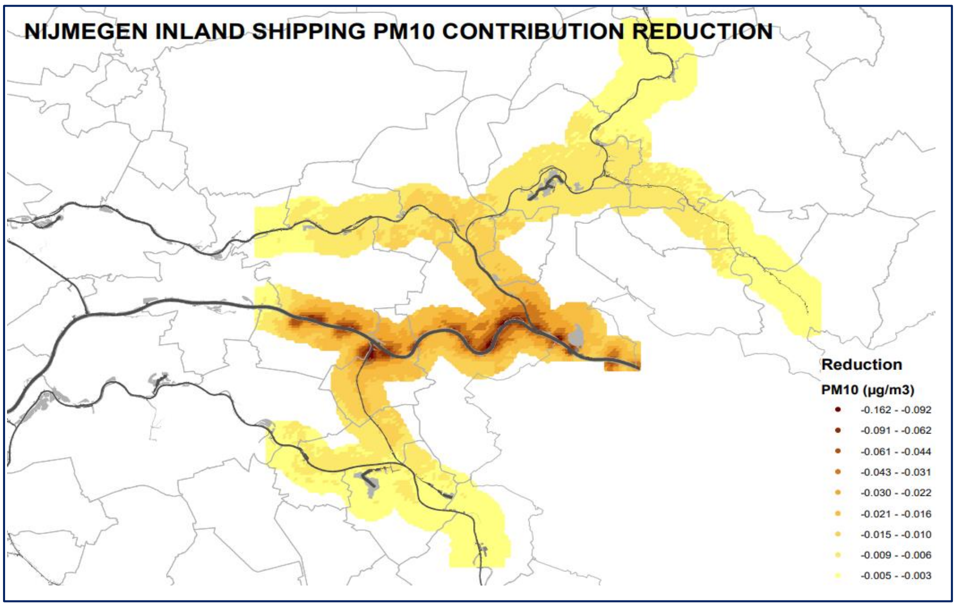
Figure 4 - Air quality (PM) improvement under 'Age + Size Restriction' scenario

These figures show that:

- A policy of banning operation at berth of auxiliary engines older than 20 years would achieve a maximum improvement of 0.3 µg/m3 in NOx and 0.04 µg/m3 in PM
- A policy of banning operation at berth of auxiliary engines older than 20 years AND of auxiliary engines on large tankers (> 68m) and large river cruisers (>85m) would achieve a maximum improvement of 0.4 µg/m3 in NOx and 0.05 µg/m3 in PM
- The improvements in air quality due to either policy become insignificant at distances of more than ~500m from the berths.

To place these figures into context, the improvements in air quality can be compared with the improvements projected under the CLINSH fleet scenario for 2035 shown below.





It can be seen that policies for improving emissions performance of fleet propulsion technologies are likely to achieve a significantly greater reduction in air pollution (up to 3 µg/m3 of NOx in some places) compared with OPS policies. This is not to say that expansion of OPS usage would have insignificant benefits to air quality, but these benefits are modest and they are localised.

6 Implementing the OPS Deployment Scenarios: Changes Needed

6.1 Policy

The return of OPS in terms of cash flows is not convincing the port authorities. It appears that OPS is not justifiable from a financial perspective. In order to enable the desired investments in OPS, grants from the EC or from national programmes are needed and/or existing financial reserves will have to be addressed. Policy makers should give more visibility to OPS in their financial instruments. The EC encourages Member States to consider using financial instruments to facilitate OPS for ships in port, by exploiting the contingencies available in EU regulation. However, some actors consider that today's incentives often do not cover all costs and do not support companies equally. Governmental support is needed to ensure a broader implementation of OPS technology.

6.2 Standards

Standardisation of shore power supply equipment is a prerequisite to enable inland vessels to connect to onshore power electricity independent of the port at which they dock. This is deemed to be an important piece in the puzzle to enable more widespread implementation and utilization of onshore power. The European Commission standardisation work aims to ensure that technical specifications for the interoperability of recharging points are specified in European or international standards by identifying the required technical specifications taking into account existing European standards and related international standardisation activities. However more attention has been paid to the standardisation of OPS for maritime shipping than for inland navigation. For example, the Commission Delegated Regulation (EU) 2018/674 of 17 November 2017 supplementing Directive 2014/94/EU referred only to standards for maritime shipping. After comments from the inland navigation sector and public authorities, the Commission has published a Delegated Regulation (EU) 2019/1745 of 13 August 2019 that includes the shoreside electricity supply for inland waterway vessels. The Delegated Regulation (EU) 2019/1745 points out that the onshore power supply for inland waterway vessels shall comply with standard EN 15869-2 or standard EN 16840 depending on energy requirements. This regulation shall take effect on 12 November 2021. This Regulation shall be binding as a whole and directly applicable in all Member States. The mandatory character of such initiatives regarding standardisation will certainly contribute to the widespread implementation of onshore power for inland navigation. Furthermore, new standards aiming to achieve full inter-operability will considerably improve economies of scale and reduce unit cost of OPS. Moreover, full inter-operability of OPS can stimulate joint projects at large scale between the European member states.

6.3 Awareness

Skippers awareness and concern about environmental and social issues of OPS is needed. The sector is reluctant of any obligation to use onshore power or a possible generator ban, which is the case in a number of ports already. Public communication has a key role in building and maintaining stakeholders engagement on this emerging technology and in making sustainable development of OPS approachable and understandable. Informed, motivated, and committed skippers can help us to achieve CLINSH's goals. Therefore, a communication platform is needed.

7 Annex 1: Estimating BAU emissions at berth

Other CLINSH actions have identified the lack of robust data on emissions at berth with a resulting high uncertainty in estimated emission levels at a specific port. Nonetheless, a methodology is required for estimating the emissions resulting from the different categories of vessels operating in a specific port, since this will determine the scale of emissions reduction that could be achieved by use of OPS. This methodology comprises the following steps:

- Quantify the number of vessel visits to the port in question, using AIS data collected in CLINSH, sub-divided into the CEMT vessel classes;
- For these CEMT vessel classes, assign the typical characteristics of the auxiliary engines installed on such vessels;
- Use data collated in CLINSH to assign emission characteristics of these typical generator models. This allows the emissions per hour while the vessel is at berth to be estimated;
- Identify the typical duration of port visits by different vessel classes, using AIS data collected in CLINSH;
- Calculate the emissions per vessel per port visit from the above data, and use the annual number of vessel visits to calculate the annual emissions from vessels at berth in the port in question.

These steps are reported below.

7.1 Number of vessels at berth

Ports authorities typically have good data on the identity of vessels visiting their port from which the number of visits per year can be calculated, sub-divided by vessel type. Within CLINSH, much of the emissions analysis has been performed by LANUV, focused on the engine statistics and emissions factors. They use a 'typical' large port activity level of 50 vessel-visits per day, to calculate the annual emissions occurring at the port, equivalent to 18,250 vessel-visits per annum. This is only intended to estimate the relative importance of emissions at berth compared with other emissions. It is a useful, reasonably high, estimate and would probably over-state the vessel visits for most ports.

Port visit data has been collected in CLINSH by HZG for several ports, using vessels' AIS transmissions, and is used in this analysis.

7.2 Auxiliary diesel-electric generator characteristics

The data available on the size and age of diesel-electric generators installed on vessels is very limited. Within CLINSH, LANUV has surveyed the available data from various countries and has reported the best figures that could be used.

Freight vessels

According to the LANUV analysis[8], when evaluating the power of the smallest generators on board in each case, a fairly homogeneous picture emerges for the class I-Va (up to 110 m length) of cargo

[8] CLINSH Deliverable: B.4 Modelling, evaluating and scenario building: Harbour monitoring, Part B: Determination of NOX and particulate matter emissions from inland vessels at berth LANUV NRW 25.06.2021

vessels. The average output is in the range of 23 - 33 kW. The smallest generators on the ships with lengths over 110 m have an average output of about 55 kW. Since there are only 10 ships in the large class (111-135 m) of the sample, the power determination for this class remains a bit more uncertain.

For the purposes of this OPS analysis, it is assumed therefore that vessels up to 110m length have an average smallest generator rating of 30kW, whilst vessels of more than 110m length have an average smallest generator rating of 55kW. However, with a small crew, the power required for services while at berth is very low. LANUV estimates 2kW an average. This means that the smallest generator on board will be operating at less than 10% load factor to supply these power levels.

Tanker vessels

For modern double-hull tankers (length classes 85-130 m), the survey of shipping companies revealed a higher power demand of about 9 kW, even if the ship is at the unloading point without using its own pumps.

In the case of tankers, it can be assumed that additional power is required when unloading the ships, because the unloading is usually carried out on the ship's side by the pumps on board, which are supplied by the largest generator on board. The LANUV analysis indicates that most tanker vessels in all size ranges have smallest generator ratings of around 55kW which would be used for loading operations (when shoreside pumps would provide most of the power required).

The largest generators on board would generally be used for driving the pumps needed for unloading operations. The power rating of these generators would be around 70kW (classes I, II and III) up to around 165kW (classes IV and Va). Class Vb vessels could have largest generator rating of 242kW.

Cabin vessels and river cruisers

For cabin vessels and river cruisers, substantially higher power is required to offer services in passenger areas. Three different vessel types and power demand ranges can be identified:

Ship‘s length	Size class	Passengers	Crew	Persons on board	Power demand
85-104 m	IV	70-100	25-30	95-130	70 kW *
105-129 m	Va	110-150	30-40	140-190	95 kW
> 130 m	Vb	140-190	45-50	195-250	115 kW

* Estimate, as data basis too small

Some smaller vessels will have 1 or 2 auxiliary engines which can operate singly or both together to provide the power required at any time. The larger vessels may typically have 3 or 4 auxiliary engines, of varying sizes, to meet the wide range of power requirements imposed by different types of operation.

7.3 Emissions characteristics of generators

The emission calculation model "TREMOD" (Transport Emission Model)[2] of the IFEU Institute, which is frequently used in Germany, maps motorized transport in Germany in terms of its traffic and mileage, energy consumption and the associated climate gas and air pollutant emissions for the period from 1960 to 2018 and in a trend scenario up to 2050. Here, the emissions from inland vessels and mobile generators are also considered.

The TREMOD figures assume a load factor greater than 25% which will not generally be the case for freight barges and tankers when at berth. Some auxiliary engines will be operating at a load factor of only a few % Therefore a correction has been made to the TREMOD emissions figures based on measurements of low-load engine consumption made by TU Delft. LANUV gives the following figures for auxiliary engine emissions at low load factor (<10%), in various engine power ratings and emissions standards[9].

	28-36 kW rated power		37-74 kW rated power	
Engine year and standard	NOx Emissions factor [g/kWh]	PM Emissions factor [g/kWh]	NOx Emissions factor [g/kWh]	PM Emissions factor [g/kWh]
Before 1981	31.5	3.5	11.4	2.7
1981-1990	33.6	2.6	13.4	1.9
1991-2002	19.6	2.8	12.7	1.3
EUII + ZKRI	15.4	0.7	9.1	0.4
EUIIIa + ZKRII	12.2	1.1	6.3	0.4
After 2018	8.5	0.03	3.5	0.025

Cargo vessels: For the emission estimates of the vessels at berth, all emissions from the generators are calculated for cargo vessels up to 110 m with the TREMOD baseline emissions adjusted for "low load" for the 28-36 kW power class, using the figures in the table above. The 135 m ships are also added to this class for the subsequent modelling.

Tanker vessels: When estimating emissions from tanker ships at berth, a distinction must be made between berthing conditions without pumping operations on the ship's side (usually loading procedures) and with pumping operations on the ship's side (usually discharging operations).

- For loading, the emission estimates of the tankers at berth without shipboard loading activities , all generators are calculated with the TREMOD base emissions of the power class 37-74 kW, adjusted for "low load" as given above;
- For unloading, the calculation is conducted with the TREMOD base emissions for the power class 130-299 kW. These emission factors are given in the table below.

	130-299 kW rated power	
Engine year and standard	NOx Emissions factor [g/kWh]	PM Emissions factor [g/kWh]
Before 1981	17.8	0.9
1981-1990	12.4	0.8
1991-2002	11.2	0.4
EUII + ZKRI	5.2	0.1
EUIIIa + ZKRII	3.2	0.1
After 2018	0.4	0.015

Cabin vessels and river cruisers

[9] Some emissions standards have been grouped together for simplicity.

These vessels also require quite high power generators to satisfy at-berth demands. For emissions estimation, the TREMOD base emissions for the power class 130-299 kW (given above) have been used.

7.4 Fleet Emissions Analysis

The average rate of emissions produced at berth across a fleet of vessels [g/hour per vessel] can be calculated using the above generator emissions characteristics, applied to the age distribution of generators installed on the fleet.

It is also possible to conduct a 'what-if scenario' calculation that assumes all engines older than 20 years would be scrapped and replaced with new Stage V engines. This provides a useful indication of what would be the impact on emissions of removing the worst polluting auxiliary engines from the fleet.

Cargo vessels

In the case of the cargo vessels, information on the year of construction of the smallest generator is available in 370 cases. The average age of these generators, depending on the ship class, is between 13 (Class Vb) and 22 years (Class IV). The actual average age of the generators for ship classes I-IV is probably significantly higher, as the year of construction of the generators is unknown for 239 ships (39%). These presumably fall predominantly into the two worst TREMOD[2]- (Transport Emission Model of the German Federal Environment Agency, UBA) emission levels (built before 1991).

NOx	Cargo Vessel (2kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	31.5	63	38.4	24		
1981-1990	33.6	67	5.9	4.0		
1991-2002	19.6	39	12.6	4.9		
EUII + ZKRI	15.4	31	18.1	5.6	18.1	5.6
EUIIIa + ZKRII	12.2	24	24.6	5.9	24.6	5.9
After 2018	8.5	17	0.2	0.0	57.3	9.7
Total				44.4		21.2

PM	Cargo Vessel (2kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	3.5	7.0	38.4	2.7		
1981-1990	2.6	5.2	5.9	0.31		
1991-2002	2.8	5.6	12.6	0.71		

EUII + ZKRI	0.7	1.4	18.1	0.25	18.1	0.25
EUIIIa + ZKRII	1.1	2.2	24.6	0.54	24.6	0.54
After 2018	0.03	0.06	0.2	0.00	57.3	0.03
Total				4.51		0.82

More than one third of these cargo vessels lacks any indication of age or emission standards of their generators, so they are assumed to pre-date the application of emissions standards. Very substantial emissions savings could be achieved by replacing all such generators with modern EU V standard models.

Tanker vessels

When estimating emissions from tankers at berth, a distinction must be made between berthing conditions without the use of pumps on the ship's side (usually loading operations) and with the use of pumps on the ship's side (usually unloading operations).

Loading: At approx. 9 kW, the power requirement is somewhat higher than for a cargo ship at berth. It is also generated via the smallest generator. The smallest generators installed on tankers generally have a higher average output in all ship classes. The length classes I (< 40 m), IV (68-87 m), Va (86-110 m) and Vb (> 110 m) show a homogeneous picture. Here, the smallest generators on board are in an average power range of 50-65 (49-66 kW).

The middle classes II and III (ship lengths 40-56 m; 56 - 68 m) are lightly populated with a total of 8 ships. Here, the generator output is only in the range of 35 kW. In this case, the determination of power remains rather uncertain.

In 236 cases of tanker vessels, information is available on the year of construction of the "smallest" generator. Depending on the ship class, the average age of the generators is between 13 and 19 years. The highest average age of the generators is 19 years for tankers in the ship length class I < 40 m. For the larger ships in the classes IV, Va and Vb, the mean age is between 12 and 15 years.

The actual average age of generators for the ship classes I-IV is probably a little bit higher, as the year of construction of the generators is unknown for 44 ships (16%). These presumably fall predominantly into the two worst TREMOD[2] emission levels (built before 1991).

Unloading: Unloading procedures usually use the "largest" generators on board to provide the energy needed for the pumps.

The "largest" generators used in tanker unloading procedures for the ship classes I, II and II are on average 66-74 kW. Ship classes IV and Va have a significantly higher mean generator output of 159 and 174 kW, while ships of the class Vb (135 m) even have a mean output of 242 kW for the "largest" generators.

For tanker vessels, information on the year of construction of the "largest" generator is available in 251 cases. Depending on the ship class, the average age of the generators is between 11 and 19 years. The largest generators of tankers reach the highest average age of 19 years in the ship class I < 40 m. For the larger ships in the classes IV, Va and Vb (85-135 m), the mean age is between 13 and

16 years. Here, too, the actual average age of the generators for ship the classes I-IV is probably a bit higher, as the year of construction of the generators is unknown for 35 ships.

NOx	Tanker Vessel Loading (9kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	11.4	102	6.7	6.8		
1981-1990	13.4	121	4.3	5.2		
1991-2002	12.7	114	12.3	14.0		
EUII + ZKRI	9.1	81.9	51.4	42.1	51.4	42.1
EUIIIa + ZKRII	6.3	56.7	25.3	14.3	25.3	14.3
After 2018	3.5	31.5			23.3	7.3
Total				82.4		63.7

PM	Tanker Vessel Loading (9kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	2.7	24.3	6.7	1.63		
1981-1990	1.9	17.1	4.3	0.74		
1991-2002	1.3	11.7	12.3	1.44		
EUII + ZKRI	0.4	3.6	51.4	1.85	51.4	1.85
EUIIIa + ZKRII	0.4	3.6	25.3	0.91	25.3	0.91
After 2018	0.025	0.22			23.3	0.05
Total				6.57		2.81

NOx	<68m Tanker Vessel Unloading (70kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	17.8	1,246	6.7	83.5		
1981-1990	12.4	868	4.3	37.3		
1991-2002	11.2	784	12.3	96.4		
EUII + ZKRI	5.2	364	51.4	187.1	51.4	187.1
EUIIIa + ZKRII	3.2	224	25.3	56.7	25.3	56.7
After 2018	0.4	28			23.3	6.5
Total				461.0		270.3

PM	<68m Tanker Vessel Unloading (70kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	0.9	63	6.7	4.2		
1981-1990	0.8	56	4.3	2.4		
1991-2002	0.4	28	12.3	3.4		
EUII + ZKRI	0.1	7	51.4	3.6	51.4	3.6
EUIIIa + ZKRII	0.1	7	25.3	1.8	25.3	1.8
After 2018	0.015	1			23.3	0.2
Total				15.4		5.6

NOx	>68m Tanker Vessel Unloading (110kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	17.8	1,958	6.7	131.2		
1981-1990	12.4	1,364	4.3	58.7		
1991-2002	11.2	1,232	12.3	151.5		
EUII + ZKRI	5.2	572	51.4	294.0	51.4	294.0
EUIIIa + ZKRII	3.2	352	25.3	89.1	25.3	89.1
After 2018	0.4	44			23.3	10.3
Total				724.5		393.4

PM	>68m Tanker Vessel Unloading (110kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	0.9	99	6.7	6.63		
1981-1990	0.8	88	4.3	3.78		
1991-2002	0.4	44	12.3	5.40		
EUII + ZKRI	0.1	11	51.4	5.65	51.4	5.65
EUIIIa + ZKRII	0.1	11	25.3	2.78	25.3	2.78
After 2018	0.015	2			23.3	0.46
Total				24.24		8.89

There are relatively few tanker vessels more than 20 years old so the great majority were fitted with generators meeting emissions regulation at least a stringent as EG II. On the other hand, the high power demand of onboard pumps for unloading means that emissions are relatively high. The what-if scenario indicates that modest emissions savings are possible by taking out of service all generators older than 20 years.

Cabin vessels & river cruisers

The level of emissions depends both on the required energy demand of the ships and on the age of the generators used and their emission behaviour. The higher the proportion of "young" generators that already meet one of the EU or CCNR emission requirements, the lower the emissions. The generators of the 110 m vessels were on average about 20 years old, only 52 % of the generator pool was already subject to the mandatory emission regulations. Most of the 135m ships in the cruise fleet were built after 2010, so that here all generators are already subject to emission regulations. This also explains the significantly lower emissions per berth hour compared to the 110 m ships.

The emissions were estimated using the emission levels according to TREMOD[2] (engine class 130-299 kW) given above. This produces the following results (NOx and PM) for each of the three length ranges of vessel:

NOx	85m Cabin Vessel (70kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	17.8	1,246	16.7	208		
1981-1990	12.4	868				
1991-2002	11.2	784	33.3	261		
EUII + ZKRI	5.2	364				
EUIIIa + ZKRII	3.2	224	50.0	112	50.0	112
After 2018	0.4	28			50.0	14
Total				581		126

NOx	110m Cabin Vessel (95kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	17.8	1,691	4.55	76		
1981-1990	12.4	1,178	13.64	160		
1991-2002	11.2	1,064	29.55	314		
EUII + ZKRI	5.2	494	27.27	135	27.27	135
EUIIIa + ZKRII	3.2	304	25.00	76	25.00	76
After 2018	0.4	38			47.73	18
Total				761		229

NOx	135m Cabin Vessel (115kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	17.8	2,047				
1981-1990	12.4	1,426				
1991-2002	11.2	1,288				
EUII + ZKRI	5.2	598	26.7	160	26.7	160
EUIIIa + ZKRII	3.2	368	73.3	270	73.3	270
After 2018	0.4	46				
Total				430		430

PM	85m Cabin Vessel (70kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	0.9	63	16.7	10.5		
1981-1990	0.8	56				
1991-2002	0.4	28	33.3	9.3		
EUII + ZKRI	0.1	7				
EUIIIa + ZKRII	0.1	7	50.0	3.5	50.0	3.5
After 2018	0.015	1.05			50.0	0.5
Total				23.3		4.0

PM	110m Cabin Vessel (95kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	0.9	85.5	4.55	3.8		
1981-1990	0.8	76	13.64	10.3		
1991-2002	0.4	38	29.55	11.2		
EUII + ZKRI	0.1	9.5	27.27	2.6	27.27	2.6
EUIIIa + ZKRII	0.1	9.5	25.00	2.4	25.00	2.4
After 2018	0.015	1.4			47.73	0.7
Total				30.4		5.7

PM	135m Cabin Vessel (115kW average power required)					
			Actual		What-if Scenario	
Engine year and standard	Emissions factor [g/kWh]	Emissions per engine [g/h]	Share of fleet	Fleet average [g/h]	Share of fleet	Fleet average [g/h]
Before 1981	0.9	103.5				
1981-1990	0.8	92				
1991-2002	0.4	46				
EUII + ZKRI	0.1	11.5	26.7	3.1	26.7	3.1
EUIIIa + ZKRII	0.1	11.5	73.3	8.4	73.3	8.4
After 2018	0.015	1.7				
Total				11.5		11.5

It can be seen that ships on cruise or hotel operations can generate quite different emissions per hour depending on the ship length/class. The lowest average emissions were 430 g/h NOX and 11.5 g/h PM from the 135 m ships that were exclusively equipped with generators of emission level EU II (or CCNR I) and EU IIIa (or CCNR II). The average age of the generators on the 135 m vessels studied was 11 years.

The ships in the 110 m length class had significantly higher average emissions per hour of 761 g/h NOX and 30.4 g/h PM. The emissions for both pollutants were somewhat lower for the 85 m length class, but this figure is likely to be less reliable due to the low number of 85 m vessels in the sample. The average age of the generators on the 85 and 110 m vessels was about 20 years.

The what-if scenario figures also show that approximately 70% reduction in NOx emissions per hour and about 80% PM emissions per hour can be achieved simply by removing from use the dirtiest (more than 20 years old) auxiliary engines when at berth.

7.5 Duration of emissions at berth

The actual quantity of emissions (kg of PM and kg NOx) discharged to atmosphere by a vessel berthing in a port depends on the number of hours when it is at berth, assuming that the vessel is operating its on-board generator continuously while at berth. Measurements of time at berth have been made for all vessels visiting a particular port, using the AIS transmissions of these vessels.

These measurements show that time at berth varies very considerably, depending not only on the vessel type (and the loading/unloading operations that it is performing while at berth) but also on the season of the year and the day of week. For example, some vessel types will often remain at berth over the weekend, showing much longer time at berth on these days than on a weekday. This behaviour is likely to depend on the amenities available at the port, and other factors which are difficult to predict.

Air quality models typically use average annual emissions to atmosphere over a model cell, to avoid undue complexity, so it is sufficient to determine average annual time at berth. This avoids the complexity of a time-varying emissions profile which would be unnecessary in a high-level study focused on strategic options for policy-makers.

Analysis by HZG has generated extensive time at berth data for vessels visiting various ports including Nijmegen, at different times of the year. The following table shows the average time at berth for different vessel classes, taken as an average of winter and summer seasons:

Vessel Class (CEMT)	Average hours at berth
I	7.3
II	8.4
III	9.0
IV	5.7
Va	8.4
Vb	7.3
VIa	6.5

Although data was also collected for the larger Class VI vessels, the number of vessels is limited. Therefore the VIa vessel berth time has been applied across VIb, VIc, VII and X classes.

For the purposes of this report, the above figures will be used as representative of vessel time at berth. A more accurate model for emissions at a specific port could use figures generated by analysis of AIS transmissions within that port. It is also possible, in principle, to collect data for different vessel types to distinguish berthing times for river cruisers and tankers, for example. The methodology for using these data to calculate emissions would, however, remain the same.

7.6 Fleet size and class distribution

The same analysis approach using AIS data from vessels can also be used to determine the yearly number of vessels of a particular class visiting a particular port. HZG has collected data for four ports within the scope of CLINSH as representative samples of different port types. For each port, vessel visits have been segregated into different vessel types and classes. Total average vessel visits per year have been These data are presented in the tables below.

Cargo Vessels

Visits/annum	Nijmegen	Rotterdam	Duisburg	Antwerp
Cargo I	318	10,125	694	6,723
Cargo II	383	8,223	146	4,468
Cargo III	2,489	31,102	2,876	13,574
Cargo IV	471	5,336	1,869	6,574
Cargo Va	2,088	21,663	5,836	20,845
Cargo Vb	423	8,282	2,508	10,351
Cargo VIa	33	1,515	88	1,069
Cargo VIb	26	467	358	1,325
Cargo VIc	18	343	131	1,190
Cargo VII	-	-	-	-
Cargo X	7	442	15	234

Tanker Vessels

Visits/annum	Nijmegen	Rotterdam	Duisburg	Antwerp
Tanker I	493	11,844	1,183	6,362
Tanker II	84	1,778	58	3,066
Tanker III	266	4,373	405	4,212
Tanker IV	256	7,037	1,380	5,526
Tanker Va	511	36,252	6,709	30,492
Tanker Vb	7	11,607	588	10,421
Tanker VIa	15	7,220	80	4,402
Tanker VIb	-	18	51	22
Tanker VIc	-	288	29	347
Tanker VII	-	-	-	-
Tanker X	-	117	51	51

Cabin Vessels & River Cruisers

Visits/annum	Nijmegen	Rotterdam	Duisburg	Antwerp
Cruiser I	26	15,078	785	2,873
Cruiser II	26	3,457	175	2,084
Cruiser III	135	2,610	110	650
Cruiser IV	22	599	29	18
Cruiser Va	511	1,153	387	642
Cruiser Vb	219	617	405	996
Cruiser VIa	-	675	4	11
Cruiser VIb	-	-	-	-
Cruiser VIc	-	55	-	7
Cruiser VII	-	-	-	-
Cruiser X	-	7	-	7

7.7 Calculation of annual emissions

The annual emissions from a vessel can be calculated from a knowledge of the average emissions per hour for that vessel, the average number of hours at berth for each port visit and the number of port visits for that vessel per annum. These data are now available, segregated by port and by vessel type/class, as reported in the earlier sections.

Straightforward application of this data implicitly assumes that all vessels run their auxiliary engines for the whole time they are at berth, without any use of OPS facilities. This is the Business As Usual case i.e. vessel owners continue to use their on-board conventional generators without restriction.

Of course, it is intended that measures will be applied to reduce emissions at berth. The impact of such measures on actual emissions at berth has been explored by applying various scenarios which are presented in the following section.

7.8 Emissions Scenarios at Berth

Three principal scenarios have been studied in order to assess the impact of different emissions reduction measures. It was noted above that the relatively small number of vessels having old auxiliary engines (pre-dating emissions standards) contribute a disproportionate amount of pollution. Therefore it makes sense to focus one scenario on measures to remove those auxiliary engines from operation at berth. This could be achieved by:

- Scrapping these old engines and replacing them with new engines that meet Stage V emissions standards or equivalent;
- Prohibiting vessel owners from running these old engines at berth, which effectively obliges them to use OPS instead.

In order to reduce at-berth emissions further, additional measures would be needed to prevent use of auxiliary engines at berth. Since the largest vessels with large at-berth loads (i.e. tankers and cruisers) tend to be responsible for large individual contributions to emissions, measures that target such vessels are likely to achieve a useful reduction in emissions.

This gives the following three scenarios for analysis and comparison:

BAU Scenario	**All vessels use their existing auxiliary generators while at berth**
Age Restriction Scenario	As BAU except that on-board auxiliary generators older than 20 years are prohibited from operation at berth
Age & Size Restriction Scenario	As for age restriction scenario with the addition that the larger vessels (tankers > 68m and cruisers > 85m) are mandated to use OPS instead of their on-board generators

Emissions in the four selected ports have been calculated for each scenario, using the analysis methodology presented above.

7.8.1 Nijmegen

Annual NOx and particulate emissions at berth under each scenario are reported below, showing the contribution of the three vessel types:

		Annual Emissions [kg/year]	
Scenario	**Vessel type**	**NOx**	**PM**
BAU Scenario	Cargo	2,274	233
	Tanker (load/unload)	1,031 / 7,350	83 / 245
	Cruiser	4,947	186
	Total	**8,253 / 14,572**	**501 / 664**
Age Restriction Scenario	Cargo	1,085	41
	Tanker (load/unload)	805 / 4,119	35 / 90
	Cruiser	1,882	50
	Total	**3,772 / 7,086**	**127 / 181**
Age & Size Restriction Scenario	Cargo	1,085	41
	Tanker (load/unload)	429 / 1,808	19 / 37
	Cruiser	219	7
	Total	**1,733 / 3,113**	**67 / 86**

It can be seen that the age restriction measures would achieve a significant (>50%) reduction in emissions from cargo and cruiser vessels. The tanker fleet is relatively new, comprising many larger vessels, so the impact of the size restriction measure has more impact on emissions.

7.8.2 Rotterdam

Annual NOx and particulate emissions at berth under each scenario are reported below, showing the contribution of the three vessel types. Given that Rotterdam is a major petrochemical distribution hub, it is likely that the majority of tanker barges will be loading, with emissions close to the lower end of the ranges shown.

		Annual Emissions [kg/year]	
Scenario	**Vessel type**	**NOx**	**PM**
BAU Scenario	Cargo	31,337	3,205
	Tanker (load/unload)	50,646 / 410,651	4,076 / 13,709
	Cruiser	107,679	4,206
	Total	**189,662 / 549,667**	**11,487 / 21,120**
Age Restriction Scenario	Cargo	14,956	570
	Tanker (load/unload)	39,529 / 225,430	1,729 / 5,033
	Cruiser	27,080	823
	Total	**81,565 / 267,466**	**3,122 / 6,426**
Age & Size Restriction Scenario	Cargo	14,956	570
	Tanker (load/unload)	9,002 / 37,979	394 / 788
	Cruiser	20,899	663
	Total	**44,857 / 73,834**	**1,627 / 2,021**

These results show similar patterns to Nijmegen, even though the port is much larger. Reductions in particulate emissions under the most restrictive scenario are very substantial (almost a factor of 10 reduction compared with BAU).

7.8.3 Antwerp

Annual NOx and particulate emissions at berth under each scenario are reported below, showing the contribution of the three vessel types:

		Annual Emissions [kg/year]	
Scenario	**Vessel type**	**NOx**	**PM**
BAU Scenario	Cargo	22,893	2,341
	Tanker (load/unload)	41,274 / 335,884	3,322 / 11,213
	Cruiser	33,036	1,263
	Total	**97,203 / 391,813**	**6,926 / 14,817**
Age Restriction Scenario	Cargo	10,926	416
	Tanker (load/unload)	32,214 / 184,284	1,409 / 4,117
	Cruiser	10,001	291
	Total	**53,141 / 205,211**	**2,116 / 4,824**
Age & Size Restriction Scenario	Cargo	10,926	416
	Tanker (load/unload)	7,039 / 29,694	308 / 616
	Cruiser	5,588	177
	Total	**23,553 / 46,208**	**901 / 1,209**

For all these ports, the reductions in particulate emissions are especially notable. This is due to a combination of two factors:

- Improving engine emissions standards have been particularly effective in reducing PM emissions;
- Emissions from tankers are high due to the amount of power needed to transfer cargo, so use of OPS for such vessels has a high impact.

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