Benchmark for seaport sustainability

Edition 2023

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Content

Glossary

Term	Explanation
CH_4	Methane
CO	Carbon-oxide
CO_2	Carbon-dioxide
$C_{20}H_{12}$	Benzo(a)pyrene
DALY	Disability-Adjusted Life Year
ESI	Environmental shipping index
GHG	Greenhouse gas
GWP	Global Warming Potential
HGV	Heavy goods vehicles
IWT	Inland waterway transport
kV	Kilovolt
N_2O	Nitrous-oxide
NH_3	Ammonia
NO_x	Nitrogen-oxides
NO_2	Nitrogen-dioxide
OPS	Onshore power supply
Pb	Lead
PM	Particulate Matter
$PM_{2,5}$	Particulate Matter smaller than 2.5 micro-metre
PM_{10}	Particulate Matter smaller than 10 micro-metre
SF_6	Sulphur hexafluoride
SO_2	Sulphur-dioxide
Tkm	Ton kilometre

Summary

This report presents the second edition of the initial benchmark for measuring the sustainability performance of seaports from 2019. This benchmark has been applied to fourteen ports in the Netherlands, other European countries and North America. The data used for the benchmark cover recent years (2019-2022) and, where possible, include an earlier reference point, usually 2010, to gain insight into long-term trends. Sustainability performance is assessed in the following areas: climate, renewable energy, air quality, water quality, maritime waste, modal split, community relations and sustainability strategy (vision). Other sustainability topics, for example use of space, safety and nature development, have not been included in this benchmark due to the difficulty of developing accurate indicators and/or obtaining available data.

The benchmark serves two purposes. Firstly, to identify the sustainability progress of individual ports. For this reason, results from the previous edition have been included. Secondly, to identify frontrunners and best practices that can stimulate the sustainable development of seaports in general. The benchmark is not suitable for ranking ports, due to their heterogeneous nature.

The primary data sources are publicly available datasets and reports published by port authorities. Other sources include reports by companies or local environmental NGOs. Port authorities were also contacted to review the data collected, with most responding, resulting in insightful benchmark results.

Improvements made

Our analysis shows that improvements have been made on several sustainability topics. These improvements include:

- Air quality in all Dutch and international ports has continued to improve over the past year. For most substances, this is a consequence of a reduction in emissions inside and outside the port. Nitrogen oxides emissions in Dutch ports are an exception: these emissions have remained stable in recent years. Nitrogen emissions from most sources decrease expect from mobility and transport which shows increases.
- Production of renewable electricity and fuels at the ports has increased. Transhipment of biomass and biofuels is also increasing, although data are less well reported. Many ports are also increasingly investing in offshore, either through connections to the national grid or through production facilities in the port.
- For some ports, mainly Bremen, Hamburg and Los Angeles, we see a significant increase in sustainable hinterland traffic.

Stability

On several sustainability topics, results are stable and no significant improvements have been made.

- The use of industrial mitigation measures, such as the use of residual heat and carbon capture and usage, has remained stable in recent years. However, many ports are investing heavily in carbon capture and storage solutions. These projects do not result in carbon reductions as yet, but could lead to significant carbon emission reductions in the coming years.

- Transport-related solutions, such as shore power and environmental zones, have remained fairly stable in recent years, although there has been some improvement. However, European ports are looking to consider shore power for maritime vessels in anticipation of European regulations. Similar legislations already apply to the Port of Long Beach and Los Angeles, where the uptake of shore power for specific vessel classes is very high.

Room for improvement

There are several sustainable issues where improvements are needed. The most important issue is the reduction of greenhouse gases.

- Port greenhouse gas emissions are mainly due to industrial facilities, power generation and transport. Results show that there have been little or no improvements in greenhouse gas emissions in recent years. This is not surprising as most port activities still rely on fossil fuels. The only exception is electricity generation, where the closure of several power plants has led to greenhouse gas reductions in some ports. Reducing greenhouse gas emissions at ports will require a change of energy carrier for industrial complexes and shipping. This transition is still in its early stages. An important step to reduce greenhouse gas emissions is to first monitor the amount of emissions. It would be beneficial to see this in practice taken up by all international ports, which is currently not the case.
- Water quality in all European ports does not meet European Water Framework Directive standards and has only improved slightly in recent years. Water quality is highly influenced by sources outside the ports. Water emissions within ports, however, have also remained fairly stable and improvements are still possible.
- Current climate change and energy transition challenges require a solid long-term sustainable strategy for ports. There is a big difference between the sustainable strategies of individual ports. Some ports have very comprehensive short-term and long-term strategies while other ports report little or nothing about their long-term goals.

Recommendations

In this second edition of the benchmark, the scope of the report has been expanded as more foreign port topics are included. Data availability is still one of the main limiting factors. Monitoring of sustainability criteria in many ports is often limited or related to official sources, as in the case of emissions and water quality. The collected data is to a large extent dependent on national or international initiatives like Emissieregistratie in the Netherlands and European Pollutant Release and Transfer Register. Data collected by ports is not streamlined and therefore heterogeneous. This makes it at times difficult to draw conclusions. Unfortunately, this second edition has not brought major improvements in the amount of data provided by port authorities and other relevant stakeholders. Gathering the data is still an intensive process with at times unsatisfactory responses.

1 Introduction

1.1 Background

Seaports are important transport hubs and can also host industrial clusters. As centres of economic activity, they also have environmental impacts. These range from negative, such as emissions, noise and land-use for transport and industry, to positive, such as providing opportunities for renewable fuels, sustainable production and economic growth.
The transition towards a zero-emission future brings new challenges and opportunities for ports that have historically relied on fossil fuels for transport and transhipment. Flows of fossil fuels will be replaced by other environmentally friendly energy carriers. Such a transition entails uncertainties and costs for ports.

In 2020, the first edition of the 'Benchmark for seaport sustainability' was published. This report focussed on the environmental performance of Dutch and some international seaports. For this first edition of the benchmark, data were collected on various sustainability criteria. The first benchmark showed that sustainable actions differ between ports and depend on port characteristics, geographical location and port size. Analysis showed that good practices could be identified for the selected sustainability criteria. For many ports, further sustainable development was required in order to reduce negative external effects. The previous edition recommended repeating the benchmark exercise in order to monitor improvements over time. As ports differ by their characteristics, improvements over time are a good criteria to measure the sustainable performance of ports. This second edition focuses on improvements of sustainable performance over time.

The Nature & Environment Federation South Holland (NZMH), a provincially oriented NGO in the Netherlands, has commissioned CE Delft to study and report on the sustainability of seaports. NMZH has actively participated in the sustainable development of the Port of Rotterdam since 1972. NMZH is a partner in many sustainable development projects and initiatives. It is also a partner in the execution of the Port Vision 2030, which describes future prospects for the port and industrial complex, including in terms of sustainable development. The Port of Rotterdam Authority[1] aims to be the most sustainable port in Western Europe by 2030. This benchmark aims to support the Port of Rotterdam in achieving this goal by presenting the sustainability performance of the Port of Rotterdam. In order to strengthen the quality of the sustainability performance, NMZH has decided to benchmark the performance of several other major seaports in the Netherlands, Europe and North America. This will provide insight into possible measures that the Port of Rotterdam, and other seaports, can take to improve their sustainability performance.

The information presented in this report could not have been available without the cooperation of the port authorities of the selected ports. The authors of this report would like to express their gratitude to the port authorities who cooperated with the data request.

[1] In this report we refer to the Rotterdam port area as Port of Rotterdam. The Rotterdam Port Authority is referred to as the Port of Rotterdam Authority. The same concept is applied to other ports.

1.2 Objective

The objective of this study is to investigate the environmental performance of various Dutch and international seaports. As ports differ widely in size and function, a direct comparison between ports is often not possible. This report therefore does not aim to score or rank ports against each other. This benchmark investigates developments over time and tries to identify success stories in different ports. By doing so, this benchmark can still provide valuable insights. These insights can be used by port authorities, policymakers and other stakeholders to adjust and improve plans and actions for more sustainable and climate-neutral ports. Additionally, the various best practices of each port can be shared so as to accelerate actions and improve outcomes towards more sustainably operating ports.
This benchmark provides a valuable tool for NGOs and other organisations in discussions and lobbying concerning the sustainable development of seaports.

1.3 Scope of the study

This benchmark focuses on recent results, from 2018 onwards. To show long-term developments, we include results from earlier years, if available. Results from the previous edition of the benchmark are also considered. If relevant, for example when important developments have taken place, these will be discussed in this edition as well.

The following ports are included:

Table 1 - Selected European seaports

Number	Port name
1	Port of Amsterdam (other NZKG ports are not included)
2	Port of Groningen
3	Port of Moerdijk
4	Port of Rotterdam
5	North Sea Port*
6	Port of Antwerp
7	Port of Barcelona
8	Port of Bremen
9	Port of Hamburg
10	Port of Le Havre
11	Port of London
12	Port of Long Beach
13	Port of Los Angeles
14	Port of Vancouver

* In 2018, the Port of Zeeland (located in Terneuzen & Flushing) merged with the Belgium Port of Ghent to form the cross-border North Sea Port. For certain topics, data availability is limited due to the differences in responsible authorities.

More limited data are available for the results of the second part. The topics covered in this report are based on the sustainability areas identified by the European Sea Ports Association (Espo, 2019) and the Dutch government (Tweede Kamer Der Staten Generaal, 2008). The topics are the following:

- **Emissions** – GHG emissions and air pollutants affect the environment by affecting human health and ecosystems, currently and in the future.

- **Mitigation measures -** Various measures are available to mitigate emissions in port areas from industrial facilities and transport activities.
- **Renewable energy -** Investments in energy transition to renewable energy sources.
- **Water quality** – chemical and ecological water quality, harmful industrial water emissions, industrial water cooling emissions.
- **Maritime waste -** concerning waste generated at sea.
- **Modal split inland transport** – modal share of land transport (trucks, pipeline, river barges, and trains) from the port.
- **Public relations** – availability of discussion platforms for neighbouring communities, hotline for complaints and other services aimed at better communication and collaboration between neighbouring communities and the port.
- **Sustainability strategy** – vision of port towards a sustainable future.

Differences compared to the previous edition:
- emissions to air and water from E-PRTR facilities are included for European ports;
- the Port of Felixstowe is no longer included as data could not be shared due to conditions specified due to private ownership;
- waste collection and sustainable strategy are included for international ports as well.

1.4 Overview of the study

This report starts with a discussion of applied Methodology in Chapter 2. Chapter 3 discusses the Characteristics of selected ports. In Chapter 4 to 12 we discuss sustainability for various topics:
- Greenhouse gas emissions (Chapter 4).
- Air quality (Chapter 5).
- Mitigation measures (Chapter 6).
- Renewable energy (Chapter 7).
- Water Quality (Chapter 8).
- Maritime Waste (Chapter 9).
- Modal Split (Chapter 10).
- Community relations (Chapter 11).
- Sustainable Strategy (Chapter 12).

The conclusions and recommendations are discussed in Chapter 13.

2 Methodology

2.1 Relevance of selected topics

Sustainability is defined by the UN as ‘meeting the needs of the present without compromising the ability of future generations to meet their own needs’. For ports, it is important to strike a balance between productivity and the environmental impact. Port activities affect several aspects of human life and other environmental topics. This chapter discusses the relevance of selected topics.

Greenhouse gas emissions

Long-term temperature fluctuations are common throughout Earth’s history. However, since the 1800s, the global temperature has been rising rapidly due to human activity. Large amounts of GHG have been emitted mainly by burning fossil fuels such as coal, oil and gas. In recent years, GHG emissions are still increasing, although measures are being taken worldwide to reduce emissions. The recent edition of the IPCC report (IPCC, 2021) discusses the effects of climate change that are already being felt through increased occurrences of extreme weather events. Unless more stringent measures are taken, global temperature will rise by more than two degrees Celsius.

The benchmark includes several criteria to measure the impact of ports on climate change. These include:
- the GHG emissions (CO_2, CH_4, N_20, SF_6) in port areas;
- mitigation measures to reduce emissions.

Air pollutants emissions and quality

Emissions of air pollutants have a detrimental effect on human health and ecosystems. Exposure to high levels of air pollution can cause a variety of adverse health outcomes. It increases the risk of respiratory infections, heart disease and lung cancer. Ecosystems are also affected by air pollutants. In the Netherlands, nitrogen deposition in particular has a negative effect on nature quality.

Several criteria have been included in the benchmark to measure the impact of ports on climate change. These include:
- The amount of emissions of the following air quality pollutants: Particulate matter (PM_{10} and $PM_{2.5}$), Nitrous oxides (NO_x), Ammonia (NH_3), Benzopyrene ($C_{20}H_{12}$), Sulphur oxides (SO_2), Carbon Oxide (CO) and Lead (PB).
- The concentrations of the following air quality pollutants: Particulate matter (PM_{10} and $PM_{2.5}$), Nitrous oxides (NO_x), Ammonia (NH_3), Benzopyrene ($C_{20}H_{12}$), Sulphur oxides (SO_2), Carbon Oxide (CO) and lead (PB).
- Mitigation measures to reduce emissions.

Renewables

In order to mitigate the effects of climate change it is necessary to switch to renewable energy sources. This involves the production of energy from renewable sources, altering production processes or switching vehicle fuels. This energy transition will bring new challenges and opportunities for ports that have traditionally been involved in the production and transhipment of fossil fuels. This topic is therefore extra relevant to the business model of ports.

We make a distinction between production and transhipment of renewable energy sources. The following types of renewable energy production sources have been considered:
- wind;
- solar;
- geothermal heat;
- certified biomass;
- biogas;
- biofuels.

As well as transhipment of the following energy carriers:
- biogas;
- biofuels;
- offshore wind;
- green hydrogen.

Water quality

Seaports operate on water connected directly to sea or inland waterways. The water will continue to flow after it has circulated within a port. Any pollutants emitted in ports will therefore affect humans, fish and other ecosystems in the region. Water quality in port areas has a direct influence on biodiversity in the port vicinity. Discharges of pollutants into surface water in port areas have a direct impact on the water quality. Pollutants can be emitted into the water by both industry and vessels. Another influence on biodiversity is the discharge of water used for cooling; the heat contained in this water disturbs ecosystems. The following criteria measure the water quality:
- water quality scores according to the European water Framework;
- emissions of a selection of pollutants into surface water and sewers.

Emissions of PFAS[2] are a topic that are currently under investigation. The dangers of these substances are not yet fully known and monitoring for these substances is still immature. For these reasons PFAS emissions are not included in this study.

Waste management

Some human waste ends up in the oceans. Especially plastics, also referred to as plastic soup, can remain in the ocean for a long time. Some plastics enter the water via rivers and beaches. Some of the waste is also from shipping. In order to mitigate illegal waste discharges, adequate wate management in ports is essential. In order to assess waste management in seaports, we use the following criteria:
- proportion of vessels depositing waste;
- volume (m^3) of waste collected per type.

We also review the waste management plans of individual ports.

2 PFAS are chemical substances produced by men which do not occur naturally in the environment.

Modal split

The environmental impact differs between various transport modes. In general, shipping and rail transport, which can carry large loads, result in lower average environmental costs compared to road haulage and aviation. The proportion of goods transported by each mode is called the modal split. Transporting a high share of goods to the hinterland by rail or barge, results in less environmental impact. Of course, the modal options are influenced by the location of the port.

This influence is limited as the companies in the port are free to choose transport modes. The following criteria have been selected for hinterland transport:
- proportion of hinterland transport per mode.

Community relations

Ports are often situated near large cities. In many cases, cities have been able to grow thanks to the workers needed in ports. The expansion of ports and cities and economic development has resulted in changing dynamics. Port areas are situated close to densely populated areas and knowledge about negative effects has increased. A sustainable port is characterised by good relations with local communities. Firstly, by improving the local environmental quality, which will benefit ecosystems and the health of local communities. The environmental quality can be improved by complaint systems for excessive noise levels or odour nuisance, active nuisance abatement or the management of local nature. Secondly, through active community engagement. This can be in the form of local committees, organised activities for locals or a fund for local projects.

Sustainable strategy

Ports operate in a global context and are subject to many changing dynamics. This includes the energy transition, the increasing Asian market share, a digitalising world and a shift towards a circular economy. In order to remain relevant at the long-term, a port needs a proper long-term sustainability strategy. We will examine the sustainability strategy of various ports and assess to what extent relevant topics are addressed.

2.2 Data gathering, sources and availability

The benchmark is largely based on quantitative information. The data has been collected incrementally. Initially, only publicly available datasets were considered. A second step was to collect data from publications of port authorities. The third step included consulting publications of companies or NGOs associated with the port authority. The fourth step included news reports and other miscellaneous sources. This resulted in a preliminary set of data for each port.

The respective port authorities have been contacted and asked to verify the data and to provide additions if available. The sources of the data for each port can be found in Appendix A. However, due to time constraints among others not all ports have been able to fully review the sources. All ports, except the port of Moerdijk, were able to assist this study to a certain extent.

Data has been collected for the years 2010–2022 where data were readily available; otherwise, data has been collected for the most recent years. Annex A provides an overview of the data collected which is not from publicly available datasets.

2.2.1 Publicly available datasets

The data collected for specific topics are based on publicly available datasets. These include Dutch and European sources. At times these datasets require some form of analysis. This mainly involves data conversions and the allocation of companies or locations to ports. The port boundaries are defined by the maps available on the websites of the port authorities. Table 2 provides an overview of the public data sources used.

Table 2 - Public sources for data gathering

Data subject	Source	Years available
Greenhouse gas and air quality emissions	Emissieregistratie	2010, 2015, 2019, 2020
Emissions of large emitters to air and water	E-PRTR	2007-2020
Air quality concentrations	RIVM	2011-2018
Water quality scores	Waterkwaliteitsportaal	2018, 2021
Water quality scores Europe	EEA	2020
Pollutant emissions to water quality	Emissieregistratie	2010, 2015, 2019, 2020
Collected maritime waste	I&W	2005, 2015-2020

2.3 Scale differences between ports

The selected ports have various functions and different focus areas. As a result, the impact of these port differs both in absolute terms and in relative terms. For example, a port with a large industrial complex will have higher emissions compared to a port that mainly focuses on logistics. The heterogeneity of port characteristics makes it difficult to draw conclusions based on the comparison of ports. A port with high emissions industry might be managed very efficiently.

In order to allow for scale differences of the various ports, several characteristics have been determined (see Table 4 to Table 6) such as size of the port, throughput and added value. Specific characteristics are used for specific topics, as shown in Table 3 for Dutch ports. For example, GHG emissions, are more related to the amount of economic activity than to the size of a port. By considering the scale of the port and its activities through different parameters, it is possible to better visualise the efforts of ports.

Table 3 - Relative comparison of topics for Dutch ports

Sustainability topic	Dependency	Related to
Climate emissions	Business activity	Added value
Air quality emissions	Business activity & space	Added value & size of port

Due to limits in data availability and quality for international ports, no figures are corrected for scale differences of international ports.

3 Characteristics of ports

3.1 Characteristics of Dutch seaports

The Netherlands has five seaports of considerable size. The ports have different focus areas that are to some extent related to their location. All of the Dutch ports house heavy industry within their boundaries, although the size differs. The ports of Amsterdam Rotterdam and Gent have a long history and their presence is closely related to the affiliated cities. The port boundaries are based on the boundaries as presented by the relevant port authorities on their websites.

Figure 1 – Location of Dutch ports

Source: Own analysis based on port maps of relevant port authorities.

Port of Amsterdam

The port of Amsterdam is one of the world's largest logistics hubs. Amsterdam is the largest port in the area called 'Noordzeekanaalgebied'. Other ports in this area are located in Zaanstad, Beverwijk, Velsen and IJmuiden, which are all considerably smaller. These smaller ports are not included in this study. Handling 80 million tonnes in cargo traffic annually (Dutch statistics office: CBS), Amsterdam is one of Western Europe's Top 5 largest seaports. The port is located on the 'Noordzeekanaal' about 20 kilometres inland. In 2022, a new lock opened called Zeesluis IJmuiden which is the largest sea lock in the world. This lock ensures that the Port of Amsterdam remains accessible to modern vessels. The main products transhipped in Amsterdam are energy products, such as petrol and coal, accounting for about 75% of the products. Other products that have a relatively high share are bulk products, such as agribulk and cacao. These products are first shipped to Amsterdam in bulk, then processed in Amsterdam and subsequently transported onwards. Focus areas for the Port of Amsterdam are: energy transition, circular economy, logistics and CO_2 reduction. A special focus area in Amsterdam are cruise vessels, of which more than 1,500 cruise vessels (river and ocean cruises) visited Amsterdam annually before the COVID-19 pandemic (Port of Amsterdam, 2021).

Groningen Seaports

Groningen Seaports is the company that manages the ports in Delfzijl and Eemshaven, which are situated in the northern province of Groningen. The ports have a direct connection to the North Sea and can be reached via road, rail and inland waterways.
The Port of Delfzijl was developed after the second world war and has a strong focus on the chemical industry due to the historical availability of natural gas and salt. This focus is expanding and includes renewable energy, biobased production and circular economy.
The Eemshaven was constructed in the 1970s and is located in a newly developed area. As a result, there is sufficient space for new industries. The focus areas at Eemshaven are energy, offshore wind and data centres. Eemshaven has an energy production capacity of 8,000 MW and produces about 30% of all energy in the Netherlands. The two ports are about 28 square km in size.

Port of Moerdijk

The Port of Moerdijk is the 5th largest seaport in the Netherlands based on throughput figures (Dutch statistics office: CBS). The Port of Moerdijk is situated inland, along the Hollands Diep river. It was developed in the 1960s and has a focus on chemicals and heavy industry. The pipeline system is directly connected to the chemicals clusters in Antwerp, Rotterdam, Zeeland, North Limburg and the Ruhr area. In Moerdijk, chemical and petrochemical companies have plenty of space for growth and the ability to pursue greening initiatives. Moreover, chemical and chemical-related companies make use of each other’s raw materials and residual streams and thus close the chains. Moerdijk is connected by inland waterways, rail, road and pipelines and offers good connectivity to the Flemish-Dutch Delta.

North Sea Port

North Sea Port is a port that is located in two countries: Belgium and the Netherlands. As its name suggests it is located along the North Sea. The port is located in the Belgium city of Ghent, along the Ghent–Terneuzen Canal, and the Dutch cities of Terneuzen and Flushing. North Sea Port started after a merger of the Dutch ports of Terneuzen and Flushing and the Belgium Port of Gent to form the North Sea Port in 2018. North Sea Port is the largest European port for transhipment of wood products, fertilizers and construction foundations. For the transhipment of non-ferrous metals, North Sea Port is the largest port worldwide. Due to limits in data availability some analysis only include the Dutch part of North Sea Port. This will be clearly indicated in tables en figures.

Port of Rotterdam

The Port of Rotterdam is Europe's largest seaport. The port owes its leading position to its outstanding accessibility by large sea-going vessels and to its intermodal connections and the 385,000 people who work in and for the Rotterdam port and industrial area. The Port of Rotterdam is a main logistical hub with access by inland waterways, rail, road and pipelines. With a transhipment of 1.6 million containers, Rotterdam is also the largest container port in Europe. The Port of Rotterdam focusses on the most important trade routes between East and West. To facilitate this, the infrastructure supports the largest vessels in the world. Transhipment and refinement of crude oil are important activities as well. Besides a major logistical function, the Port of Rotterdam also contains a large complex of industrial and chemical industries.

Scale

The various functions and characteristics of the ports are also shown in the scale of the ports. Table 4 shows the size, excluding water surface, in square km of the various ports.

Table 4 - Size (square km) of ports 2021

Square km	2021
Amsterdam	19
Groningen	28
Moerdijk	26
Rotterdam	80
North Sea Port	44

Rotterdam is the largest port in size while North Sea Port is the second largest port in size in the Netherlands. Groningen and Moerdijk are comparable in size. Amsterdam is the smallest port in size and it mainly has a logistical function, as is exemplified by Table 5. The throughput in Amsterdam is the second highest in the Netherlands, followed by the Dutch part of North Sea Port, which has remarkably stable throughput figures. Throughput in the Port of Groningen has increased significantly since 2010.

Table 5 - Total marine related throughput (million tonne) of ports between 2010 and 2021

Mil Tonne	2010	2018*	2019	2020	2021
Amsterdam	73	82	87	74	71
Groningen	3	14	13	10	13
Moerdijk	6	7	7	7	7
Rotterdam	405	469	469	437	469
North Sea Port	34	70	71	64	69

* In 2018 Zeeland Seaports and the Port of Ghent merged to become North Sea Port.

A third way to compare ports is by the added value they produce. Added value is the difference between purchase price of inputs and the price at which the processed products are sold. Added value is thus the additional value that is created by the processes performed by a company. It is possible to calculate the added value of a port area by summing up the added values of the companies inside a port area. Added value is a proxy for the economic scale of a port. Erasmus University annually reports the added values of various port areas in the Netherlands (Streng et al., 2021). The results are shown in Table 6.

The Port of Rotterdam has the highest added value in the Netherlands, unsurprisingly since Rotterdam is the largest port in Europe. Groningen and Moerdijk are the ports with the lowest added value. The added value of the ports depends on more than the throughput or square kilometres of a port. For example, the Dutch part of the North Sea Port only has about half the tonnes in throughput compared to the Port of Amsterdam. However, the added value in the Dutch part of North Sea Port is significantly higher, which is most likely due to the large chemical complex situated in. This creates more added value from transhipped goods than the goods that are transhipped in the Port of Amsterdam.

Table 6 - Direct added value in million € for ports between 2010 and 2020

Mil Euro	2010	2015	2016	2017	2018	2019	2020
Amsterdam	1,645	2,069	2,125	2,159	2,550	2,370	2,220
Groningen	814	1,087	1,235	1,323	1,420	1,490	1,520
Moerdijk	1,276	1,376	1,398	1,471	1,580	1,090	1,050
Rotterdam	11,143	11,962	13,716	14,689	14,220	14,920	14,610
North Sea Port (NL)	3,119	3,241	3,477	3,594	2,650	2,730	2,650
North Sea Port (BE)	n/a	n/a	n/a	n/a	n/a	4,374	4,550
North Sea Port total	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**7,104**	**7,200**

3.2 Characteristics of international ports

This section discusses the characteristics of the selected international ports. The ports were included in the previous edition of this benchmark (CE Delft, 2020). The Port of Felixstowe is not included because during the previous edition, the port was unable to share data in the context of its private ownership. The ports are situated in north west Europe, the south of Europe (Barcelona) and the west coast of North America. All of the ports have made efforts to become more sustainable. Figure 2 shows an overview of the locations of the ports in north west Europe which are located.

Figure 2 - Location of ports in north west Europe

Source: Own analysis based on port maps of relevant port authorities.

Port of Antwerp

Located in Belgium, the Port of Antwerp is the second largest port in Europe after the Port of Rotterdam. In 2022, the Port of Antwerp merged with the Belgian Port of Zeebrugge to form the Port of Antwerp-Bruges. Because this study mainly uses historical data, our analyses will focus on the Port of Antwerp. The Port of Antwerp is located along the Western Scheldt river, about 80 kilometres inland. It is connected by road, rail and inland waterways, as well as shortsea and pipeline transport. The main types of freight transhipped in Antwerp are containers and liquid bulk. Antwerp is also a leading breakbulk port in Europe. Antwerp is not only the European market leader for the handling of steel and fruit, but also the largest port in the world for the coffee trade. The Port of Antwerp contains a large industrial sector including a major petro (chemical) company cluster. The port also contains a nuclear power plant. The Port of Antwerp is situated north of the city of Antwerp with over half a million inhabitants.

Port of Barcelona

Located on the Mediterranean Sea, the Port of Barcelona is one of the largest ports in Spain. The Port of Barcelona covers 110 square kilometres and includes three areas, the Old Port, the commercial/industrial port and the logistics port. The Port of Barcelona is one of the largest ports in terms of passenger transport, it has ferry connections to locations across the Mediterranean and is often visited by cruises. The port specialises in containers and dry cargo. The Port of Barcelona is home to manufacturers of textiles, pharmaceuticals, chemicals, electronics, and motors. The port does not house a large industrial site as some of the other ports do.

Ports of Bremen

The ports of Bremen, located in Bremen and Bremerhaven, are situated at the mouth of the river Wezer in the North Sea. The port is connected by road, rail and inland waterways and is able to transport almost every type of cargo. The ports of Bremen mainly transport general cargo: containers and vehicles. After Zeebrugge it is Europe's second-largest terminal for automobile transhipment. The ports of Bremen do not house a large industrial or chemical industry. It does include an offshore wind industry and is Germany's industry leader in fish and food processing. With a size of 30 square km, the Ports of Bremen are average in size.

Port of Hamburg

The Port of Hamburg is situated along the Elbe river, about 110 kilometres from its mouth in the North Sea. It is also connected to Scandinavia and the Baltic Sea via the Kiel Canal. The Port of Hamburg is the third largest port in the Hamburg - Le Havre range with a market share of over 11% in 2020 (Port of Rotterdam, 2021a). The Port of Hamburg is the largest port in Germany. It has a focus on containers, although other types of cargo are handled as well. The port also plays a crucial role in supply and waste disposal logistics for industry in Hamburg and the Metropolitan Region. The port contains industrial enterprises and manufacturing industries, including a copper smelter and manufacturers of ships, aircraft and other machinery. Other important businesses are renowned industrial firms in the energy, raw materials, drive technology, shipbuilding, mechanical engineering and fertilizer industries.

Port of Le Havre

The Port of Le Havre is the most southern port in the Hamburg – Le Havre (HLH) range, a range of the largest seaports situated in North Western Europe. Le Havre is responsible for about 4.5% of throughput in this range (Port of Rotterdam, 2021a). Le Havre is the second largest port in France after Marseille. It is located directly by sea on the outlet of the river Seine. The main transport commodities are containers, Ro-Ro and cereals. Besides having a logistical function, the Port of Le Havre also houses an industrial complex. The total size of the port is about 100 square km and a large part is available for industry. It contains the largest chemical platform in France and the entire Seine Valley entrance is the largest industrial region in France. Various industrial companies are situated in the industrial and logistic area, including a car assembly factory, a refinery, a factory for aviation technologies, a factory and a waste incineration and recycling plant.

Port of London

The Port of London is situated along the River Thames and encompasses the area from London to the mouth of the North Sea. Today, the Port of London comprises over 70 independently owned terminals and port facilities, including DP World's London Gateway, the Port of Purfleet and Tilbury. The Port of London is the largest port in the United Kingdom. During much of the 20th century, the Port of London Authority owned and operated many of the docks and wharfs in the port, but these have all now been closed or privatised. Today the Port of London Authority acts mainly as a managing authority for the tidal stretch of the River Thames, ensuring safe navigation and the well-being of the port and its activities.

Port of Long Beach

The Port of Long Beach is located in the city with the same name in California along the western coast of the United States. The Port of Long Beach is adjacent to the Port of Los Angeles. The port is an important transhipment port for goods to and from Asia. Like the Port of Los Angeles, it specialises in container transport and car imports. The port is about thirteen square kilometres in size. Together with the Port of Los Angeles the Port of Long Beach is responsible for 32% of containerised trade in the United States (Port of Los Angeles, 2022a). The port supports businesses in the trade, logistics and real estate sectors, including trucking firms, customs brokers and freight forwarders, shipping lines, warehouses and other enterprises. The port does not house an industrial complex.

Port of Los Angeles

The Port of Los Angeles is located along the western coast of North America near the city of Los Angeles and next to the Port of Long Beach. The Port of Los Angeles is the largest container port in North America. The port has a 16% market share of the United States (Port of Los Angeles, 2022a). Besides containers, automobiles are often transported via Los Angeles. Bulk goods are less predominant for the Port of Los Angeles. The size of the port is about seventeen square kilometres of land and the port does not house an industrial complex. The Port of Los Angeles has good rail and road connections.

Port of Vancouver

The Port of Vancouver is about the same size as the next five largest Canadian ports combined. Home to 27 major terminals, the port is able to handle the most diversified range of cargo in North America: bulk, containers, breakbulk, liquid bulk, automobiles and cruise vessels. The Port of Vancouver is situated along multiple distinct areas along Canada’s west coast and is a key port for trade with Asia. The Port of Vancouver is connected by rail and road to the hinterland. It is the third largest port in North America by tonnes of cargo, and the largest with respect to exports.

Scale

Table 7 shows the size of ports in square kilometres. There are large differences in size of ports. Ports which also house an industrial complex, such as Antwerp and Le Havre, are significantly larger.

Table 7 - Size (square km) of ports 2021

	Square km
Antwerp	115
Barcelona	11
Bremen	46
Hamburg	43
Le Havre	100
London	52

	Square km
Long Beach	14
Los Angeles	30
Vancouver	8

Sources are provided in Annex A.2.

Table 8 shows the throughput of the various ports. The ports of Antwerp, Long Beach and Vancouver are the largest ports. The throughput in all ports has increased except the Port of Hamburg.

Table 8 - Total marine related throughput (million tonne) of ports in 2010 and 2021

Mil Tonne	2010	2021
Antwerp	178	240
Barcelona	43	47
Bremen	69	70
Hamburg	131	129
Le Havre	70	93
London	48	52
Long Beach	158	222
Los Angeles	74	90
Vancouver	118	146

Sources are provided in Annex A.2.

Table 9 shows the added value for a selection of international ports. The information is only available for a selection of ports. Also, the scope in which added values calculated possibly differ between ports. For this reason the information cannot be used to provide emissions relative to added value for the international ports.

Table 9 - Direct added value in million € for ports between 2021

Mil Euro	2021
Antwerp	21,000
Barcelona	n/a
Bremen	n/a
Hamburg	9,800
Le Havre	n/a
London	3,221
Long Beach	n/a
Los Angeles	n/a
Vancouver	n/a

Sources are provided in Annex A.2.

4 Greenhouse gas emissions

GHG emissions due to combustion of fossil fuels are the main cause of climate change. In order to mitigate climate change, it is important to reduce GHG emissions. In this chapter, we will delve into GHG emissions in port areas. We start with a detailed discussion of the results for Dutch ports, firstly for carbon dioxide and secondly for other greenhouse gases. We will discuss international ports separately due to limited data availability. This chapter concludes with a section containing conclusions.

4.1 Carbon dioxide

Carbon dioxide (CO_2) is the best-known GHG. In the Netherlands, Emissieregistratie reports carbon dioxide emissions in 1x1 km squares for 2015, 2019 and 2020. For 2010, Emissieregistratie reported the emissions in 5x5 km squares, resulting in a (small) overestimation as more emissions from outside the port area are taken into account. To minimise this overestimation, CO_2 emissions have been calculated by multiplying them with the average difference between 1x1 and 5x5 data for 2015, 2019 and 2020 per port. CO_2 is primarily emitted during the combustion of fuel, which could be fossil fuels (coal) or renewable sources (biomass). CO_2 is the most important GHG, having a share of total GHG emissions for the Netherlands of 83.6% in 2020 and 84.0% in 2021 (CBS, 2021). The total CO_2 emissions in kilotons are shown in Table 10.

Table 10 - CO_2 emissions in port areas of the selected Dutch ports

Kton CO_2	2010	2015	2019	2020
Amsterdam	4,556	6,014	4,998	2,869
Groningen	7,352	10,541	12,403	9,449
Moerdijk	5,288	3,894	4,966	4,823
Rotterdam	29,128	32,166	28,834	26,991
North Sea Port -NL	14,037	11,423	9,745	10,389
North Sea Port -BE	n/a	n/a	12,800	11,111
North Sea Port	n/a	n/a	22,545	21,500
Total	**60,361**	**64,038**	**73,746**	**65,632**

All ports experienced a decline in CO_2 emissions between 2010 and 2020, except for Groningen Seaports as new port areas were developed between 2010 and 2020. The five ports together experienced a decrease in CO_2 emissions of 16.1% between 2010 and 2020. In 2020, total CO_2 emissions were 51,521 kton, which equals around 39.4% of total CO_2 emissions in the Netherlands in 2020.

Sources of emissions

Table 11 shows which sectors are the main emitters of carbon dioxide for the years 2010, 2015, 2019 and 2020. The energy sector is the sector with the highest emissions with 21 Mton of emissions of CO_2, followed by chemical industry (13 Mton), refineries (10 Mton) and waste disposal (5 Mton). These four sectors account for more than 91% of the CO_2 emitted in port areas.

Table 11 - Main sources of CO_2 emissions in Dutch* port areas

Kton CO_2	2010	2015	2019	2020
Agriculture	536	28	30	29
Chemical industry	11,615	10,825	11,938	13,178
Construction	65	19	16	23
Consumers	1,794	230	224	138
Drinking water supply	1	0	0	0
Energy sector	26,190	33,343	28,026	20,997
Mobility and transport	3,364	2,165	2,334	2,584
Nature	-	-	-	-
Other industry	1,616	1,071	1,013	963
Refineries	9,995	11,178	11,472	10,439
Sewage treatment	58	73	86	87
Trade, services and government	1,036	525	974	854
Waste disposal	4,090	4,582	4,833	5,229
Total	**60,361**	**64,038**	**60,946**	**54,521**

* Emissions from Belgian part of North Sea Port are not included.

The sectors that are the main emitters are those with large companies located within the port area. In Section 4.3, we discuss the emissions of industrial facilities that are required to report emissions[3]. Almost 80% of the emissions of Groningen Seaports in 2020 are caused by companies in the energy sector. The Port of Groningen contains an energy production complex which includes four power stations powered by gas, coal and biomass. Emissions from this energy cluster total about 7.45 Mton CO_2 in 2020. The CO_2 emissions from the single power station have decreased over the past years. In 2017, this power station caused about 60% of the emissions of Groningen Seaports. This percentage decreased to around 32% in 2020. In Annex B, a large decline of CO_2 emissions is visible for the port of Rotterdam between 2015 and 2019. This can be explained by a closure of two power stations in 2017.

Relative emissions

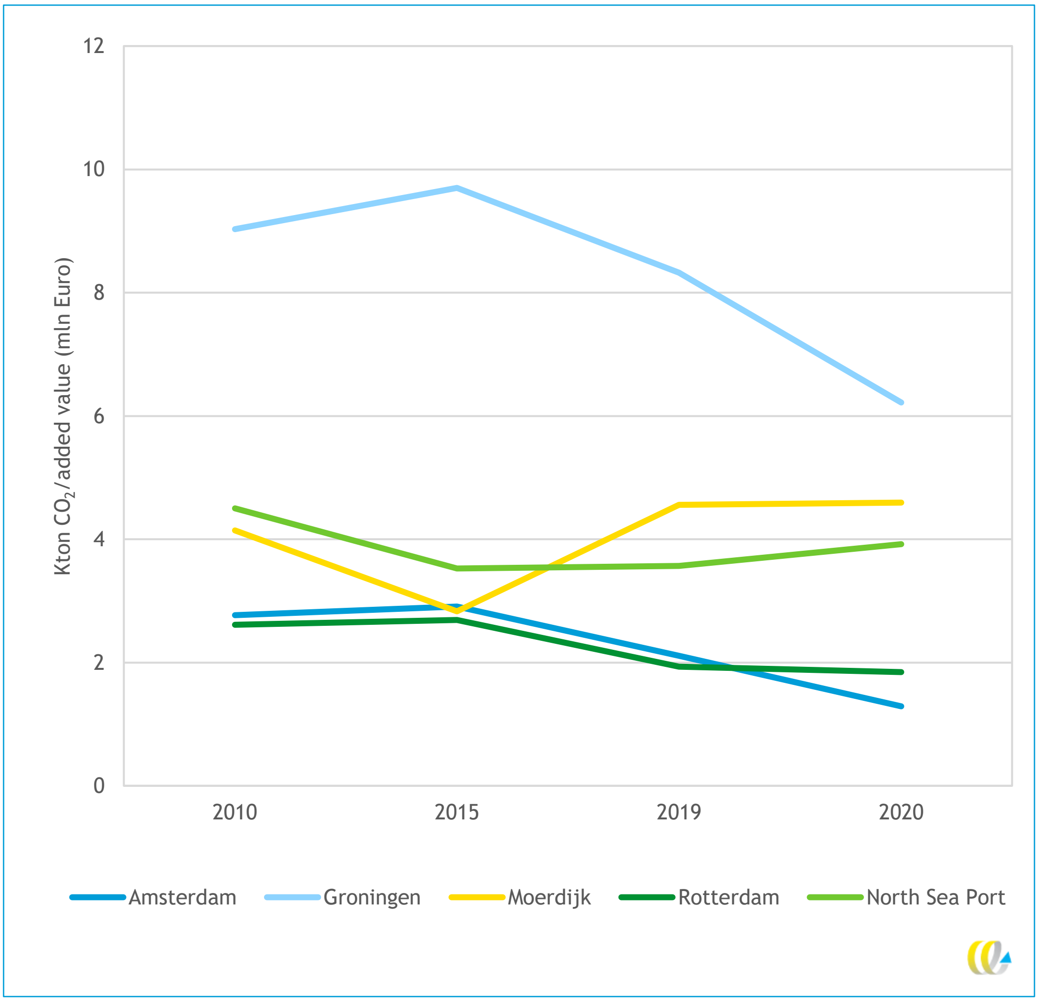
Absolute CO_2 emissions tell us a lot about each port, but these values do not take into account various elements, such as the size of the port, efficiency and throughput. Ports can grow in size or activity by more than their increase in CO_2 emissions. This means that their relative CO_2 emissions decrease, as more is being produced with a lower rate of increase (or maybe even a decrease) in the level of CO_2 emissions. There are multiple ways to quantify the amount of production. Throughput provides information regarding maritime activity, but this does not include industrial activity, which is another function of ports.

Figure 2 shows the CO_2 emissions relative to the added value of each port. Groningen Seaports is still the largest relative emitter when comparing CO_2 emissions to added value. The Port of Moerdijk surpassed North Sea Port (Dutch part) in 2019, taking the second spot. The North Sea Port (Dutch part) takes third place. The Port of Rotterdam, the largest port in the Netherlands, surpassed the Port of Amsterdam in 2020 and takes number four position. The Port of Amsterdam has the lowest CO_2 emissions relative to added value. The steep decline of Groningen Seaports after 2015 can be explained by a significant increase in added value after 2015 and a large decrease in CO_2 emissions between 2019 and 2020. The Port of Moerdijk experienced a sharp decrease between 2010 and 2015 and then

[3] https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.htm

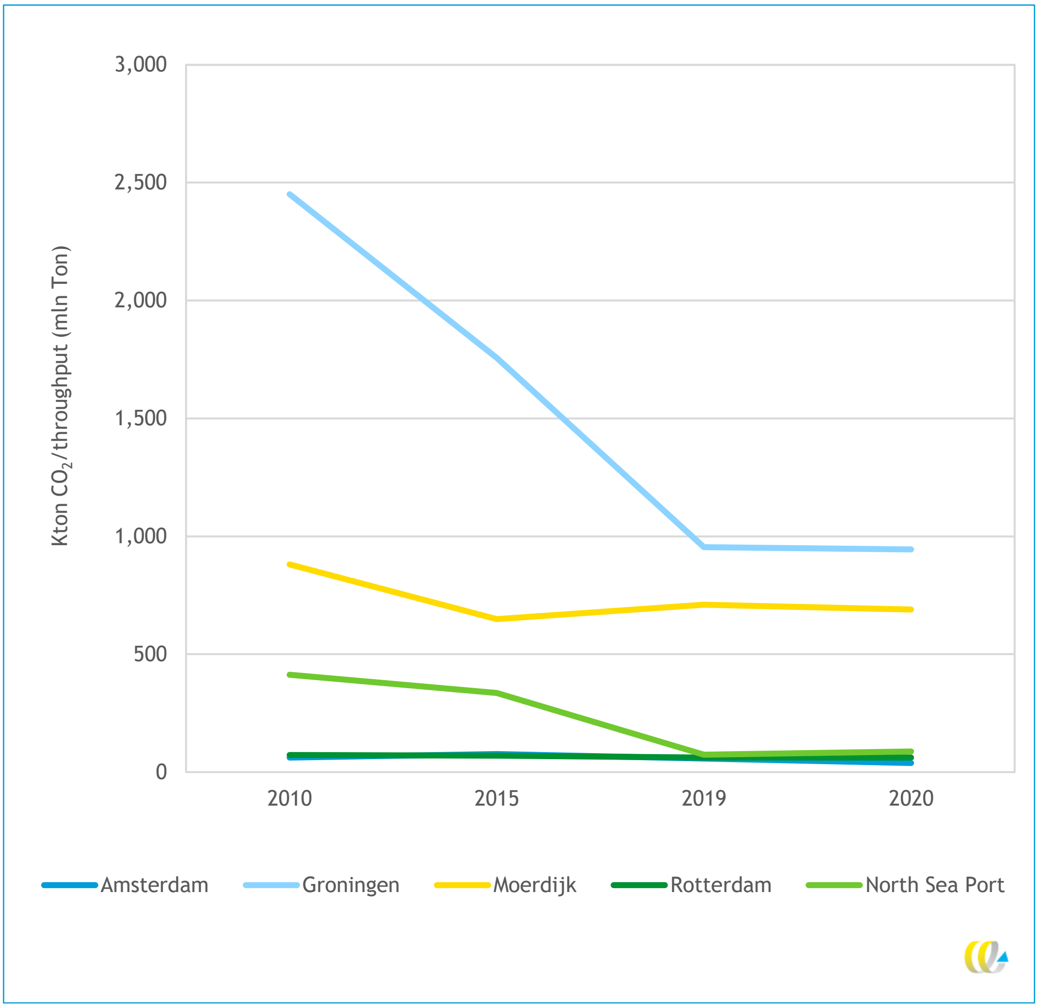
a steep increase between 2015 and 2019 in relative CO_2 emissions. The added value of the Port of Moerdijk decreased between 2010 and 2015, and then increased again between 2015 and 2019 and the same pattern is visible for CO_2 emissions. The North Sea Port and the Port of Rotterdam remained reasonably stable over the years. The Port of Amsterdam shows a steep and continuous decline over the years, which corresponds to the modest decline in CO_2 emissions over the years as well as the modest increase in added value.

Figure 3 - CO_2 emissions relative to added value in port areas in the Netherlands



According to CLO (Rijksoverheid, 2018), waste management is the sector with the highest CO_2 intensity, followed by the petroleum industry and energy production. This is mainly due to waste incineration producing a lot of CO_2 emissions, but generating very little added value. Groningen Seaports has a very large energy production industry, which explains why the carbon intensity is so high. The ports of Amsterdam, Rotterdam and the North Sea Port have relatively low carbon intensities, which means that more money is made for every emitted kilogram of CO_2 emissions. Figure 3 shows the relative CO_2 emissions compared to the throughput.

Figure 4 - CO_2 emissions in port areas in the Netherlands relative to throughput (Mton)



Groningen Seaports has the highest relative CO_2 emissions relative to throughput, as it does for CO_2 relative to added value. There is a large decrease for Groningen Seaports between 2010 and 2019. The CO_2 emissions rose between 2010 and 2019, but the total throughput approximately doubled between 2010 and 2015, and between 2015 and 2019 the throughput increased by around 117%. As in Figure 2, the Port of Moerdijk has the second highest CO_2 emissions relative to throughput, but remains fairly stable. The North Sea Port (Dutch part), the Port of Rotterdam and the Port of Amsterdam all remain around the same level.
The only noteworthy development is the steep decline of the Dutch part of the North Sea Port between 2010 and 2019 due to a constant decrease in CO_2 emissions and the merger in 2018.

4.2 Other Greenhouse Gases

Methane

Methane (CH_4) is a greenhouse gas with a global warming potential 25 times stronger than carbon dioxide. Methane is being emitted from a variety of anthropogenic sources, such as agriculture, coal mining, wastewater treatment and oil and natural gas systems, but also from natural sources, such as wetlands, swamps and oceans. Table 12 lists the CH_4 emissions for all analysed Dutch ports for the years 2010, 2015, 2019 and 2020. Emissieregistratie has reported methane data based on 5x5 km data, which is less accurate than 1x1 data in terms of measuring of the emissions.

Table 12 - CH_4 emissions in port areas of selected Dutch ports

Kton CH_4	2010	2015	2019	2020
Amsterdam	4.8	9.8	4.5	4.2
Groningen	0.8	1.0	1.0	0.9
Moerdijk	3.1	2.7	1.8	1.6
Rotterdam	5.8	7.9	8.1	7.4
North Sea Port - NL	6.0	7.0	6.4	6.2
North Sea Port - BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**20.4**	**28.3**	**21.8**	**20.4**

The Port of Rotterdam has the highest methane emissions, followed by the North Sea Port (Dutch part), the Port of Amsterdam, the Port of Moerdijk and lastly Groningen Seaports. This is not consistent with the sizes of the ports, as the Port of Amsterdam is the smallest port based on size, but emits almost the same amount of methane as double the emissions of the Port of Moerdijk plus one time the emissions of Groningen Seaports. Groningen Seaports is the third largest port, but has by far the lowest methane emissions. In 2020, all ports emitted 20.4 kton methane, which is only a small fraction (0.1%) of the total methane emissions of 19 Mton in 2020 in the Netherlands, in contrast to CO_2 emissions, where ports contributed about 39.4% of total Dutch CO_2 emissions (CBS, 2021).

Table 13 shows which sectors are the largest contributors of methane. The main emitting sectors within the port areas are waste disposal (8.2 kton), agriculture (5.2 kton) and the energy sector (1.8 kton). It is interesting to see that agriculture plays such a large role within the port areas. This is caused by farms located just outside the port area, which are included due to the 5x5 scope of Emissieregistratie. Emissions from waste disposal occur primarily in the Dutch part of North Sea Port (4.4 kton), the Port of Amsterdam (2.6 kton) and the Port of Moerdijk (1.1 kton), as can be seen in Annex B.

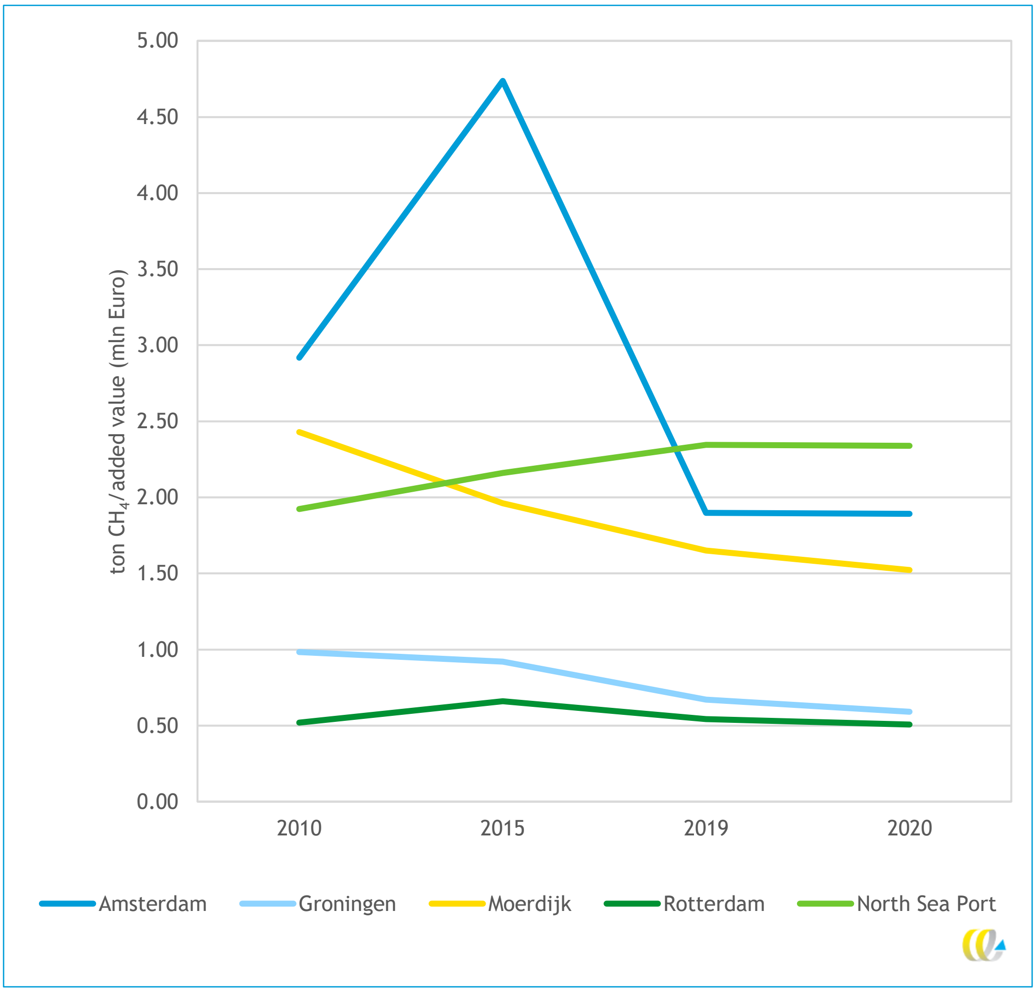
Table 13 - Important sources of CH_4 emissions in port areas

Kton CH_4	2010	2015	2019	2020
Agriculture	-	5.1	5.7	5.2
Chemical industry	0.9	0.9	0.7	0.7
Construction	0.0	0.0	0.0	0.0
Consumers	1.7	1.2	1.1	1.0
Drinking water supply	0.1	0.1	0.1	0.1

Kton CH_4	2010	2015	2019	2020
Energy sector	2.4	2.4	2.0	1.8
Mobility and transport	0.3	0.3	0.4	0.3
Nature	1.1	0.9	0.9	0.9
Other industry	0.3	0.2	0.3	0.3
Refineries	2.1	0.5	0.5	0.5
Sewage treatment	0.9	1.0	1.1	1.1
Trade, services and government	0.3	0.2	0.2	0.2
Waste disposal	10.5	15.6	8.7	8.2
Total	**20.4**	**28.3**	**21.8**	**20.4**

Figure 4 shows the methane emissions of the port areas relative to the added value. The Port of Amsterdam had the highest relative methane emissions compared to added value, until 2019 when it was surpassed by the Dutch part of North Sea Port. The Port of Rotterdam has the highest absolute methane emissions, but scores the lowest relative to added value.

Figure 5 - CH4 emissions in port areas in the Netherlands relative to added value



Nitrous oxide

Nitrous oxide (N_2O) has a global warming potential 298 times higher than CO_2. Nitrous oxide is naturally emitted by oceans, rainforests and wetlands, due to microorganisms such as denitrifying bacteria and fungi. Non-natural processes include fertilized agricultural soils and livestock manure, fossil fuels and industrial and chemical processes based on nitrogen. Table 14 displays the N_2O emissions for all researched Dutch ports for the years 2010, 2015, 2019 and 2020. The data are on a 5x5 km scale.

Table 14 - N_2O emissions in port areas of selected Dutch ports

Kton N_2O	2010	2015	2019	2020
Amsterdam	0.12	0.19	0.18	0.16
Groningen	0.01	0.16	0.18	0.16
Moerdijk	0.17	0.19	0.17	0.14
Rotterdam	0.32	0.44	0.67	0.49
North Sea Port -NL	0.85	0.88	1.00	0.65
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**1.48**	**1.86**	**2.20**	**1.59**

Total nitrous oxide emissions increased between 2010 and 2019. Between 2019 and 2020, nitrous oxide emissions almost decreased to 2010 levels. The COVID-19 pandemic could be a reason for this decrease, as added value and throughput also decreased, especially in 2020. The Dutch part of the North Sea Port was the largest nitrous oxide emitter in 2020 (0.65 kton), followed by the Port of Rotterdam (0.49 kton). The Port of Amsterdam, Groningen Seaports and the Port of Moerdijk are all around the same level (0.16, 0.16 and 0.14, respectively). Table 15 displays the sectors that emit the most nitrous oxide.

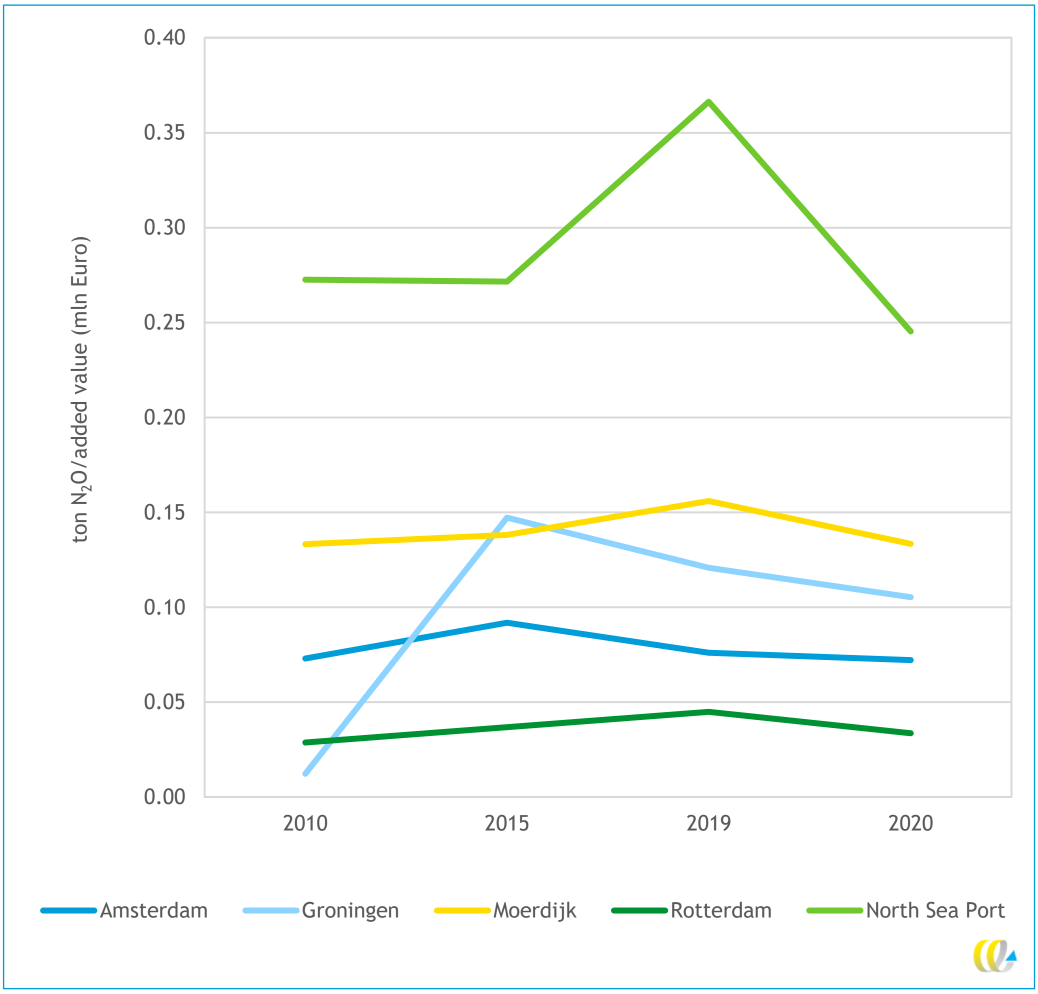
Table 15 - Main sources of N_2O emissions in port areas

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.25	0.26	0.26
Chemical industry	0.81	0.76	0.88	0.54
Construction	0.00	0.00	0.00	0.00
Consumers	0.03	0.03	0.03	0.03
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.18	0.35	0.26	0.18
Mobility and transport	0.11	0.12	0.14	0.14
Nature	0.02	0.02	0.02	0.02
Other industry	0.00	0.00	0.00	0.00
Refineries	0.06	0.06	0.37	0.20
Sewage treatment	0.03	0.03	0.03	0.03
Trade, services and government	0.01	0.01	0.01	0.01
Waste disposal	0.23	0.23	0.20	0.19
Total	**1.48**	**1.86**	**2.20**	**1.59**

The chemical industry contributes the largest amount of nitrous oxide emissions. The Dutch part of the North Sea Port has the largest share of chemical industry (0.54 kton), as can be seen in Annex B. Other sectors that emit high levels of nitrous oxide are agriculture (0.26

kton), refineries (0.20 kton), waste disposal (0.19 kton) and the energy sector (0.18 kton). The Dutch part of the North Sea Port hosts a large chemical industry complex, which explains the high number of nitrous oxide emissions. Unlike carbon dioxide and methane, nitrous oxide has increased between 2010 and 2019. The total nitrous oxide emissions of the Netherlands are 6.9 Mton, which means that nitrous oxide emissions within the port areas are 0.02% of the national total (CBS, 2021). Before 2005, nitrous oxide emissions used to be a lot higher. The reduction has been realised by N_2O reduction measures for the production of nitric acid and high reductions of nitrous oxide in the agricultural sector (Rijksoverheid, 2019). Figure 5 displays nitrous oxide emissions relative to the added value of ports.

Figure 6 - Relative N_2O emissions in port areas in the Netherlands relative to added value



Relative nitrous oxide emissions are the highest for the Dutch part of the North Sea Port. The steep decline between 2019 and 2020 is due to emissions declining slightly, but added value declining by about 35%. The Port of Moerdijk, the Port of Amsterdam and the Port of Rotterdam remain pretty stable over the years. Only Groningen Seaports experienced a steep increase between 2010 and 2015, because its added value remained reasonably stable, but nitrous oxide emissions increased substantially between 2010 and 2015.

Sulphur hexafluoride (SF_6)

Sulphur hexafluoride (SF_6) has a global warming potential that is 22,800 times higher than that of CO_2. It used to be applied as an isolating gas in double glass, in spare wheels, in tennis balls and the soles of sneakers, but these uses have been forbidden in the EU since 2007. It may still be used in the electrical industry, mainly in high voltage installations. Other emissions occur in the semiconductor industry and in processes where sulphur hexafluoride is used for cleaning. Table 16 shows the sulphur hexafluoride emissions for all port areas of the analysed ports. The data are projected on a 5x5 km scale.

Table 16 - SF_6 emissions in port areas of the selected Dutch ports

Ton SF_6	2010	2015	2019	2020
Amsterdam	0.31	0.29	0.27	0.27
Groningen	0.01	0.01	0.02	0.04
Moerdijk	0.01	0.01	0.01	0.01
Rotterdam	0.44	0.41	0.39	0.39
North Sea Port -NL	0.04	0.03	0.03	0.03
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**0.80**	**0.75**	**0.73**	**0.74**

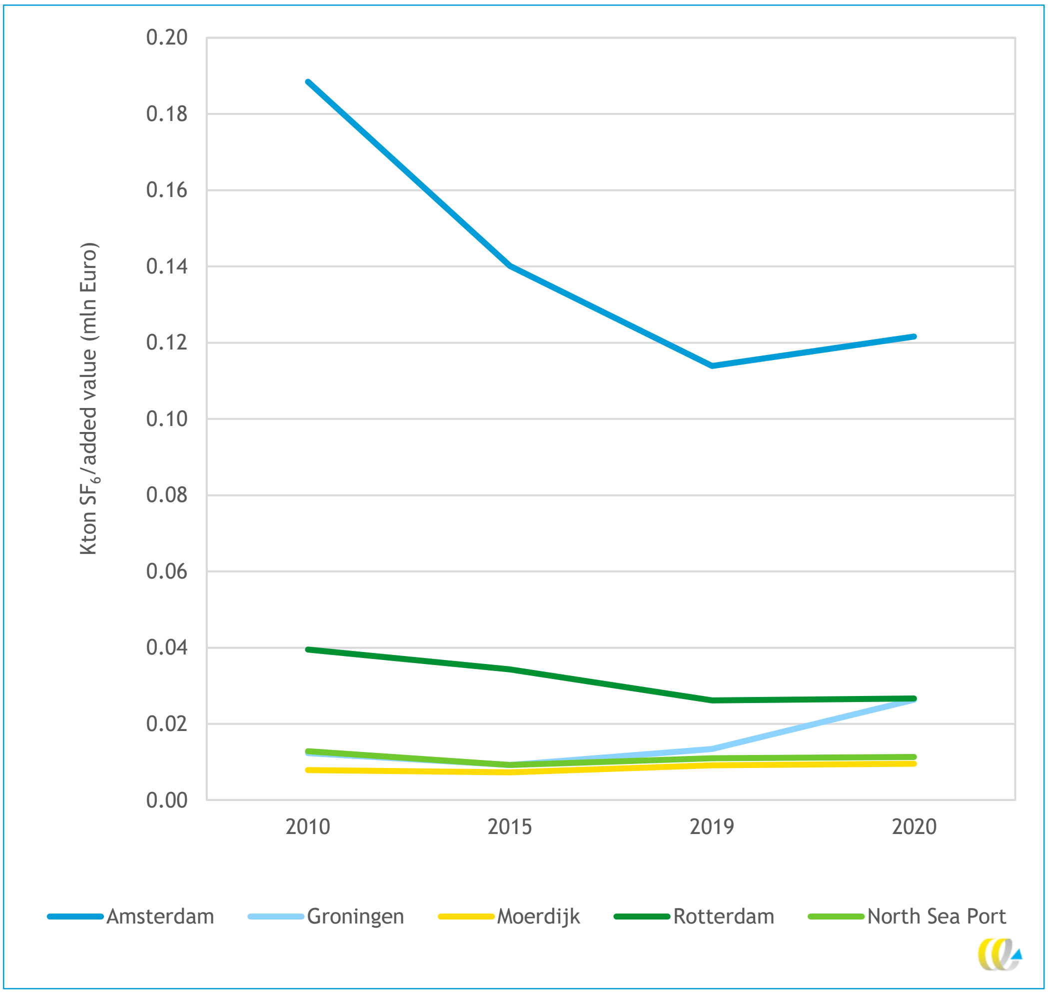
The Port of Rotterdam has the highest SF_6 emissions, which is hardly surprising as the Port of Rotterdam is the largest port. More surprisingly, the Port of Amsterdam takes second place, as it is the smallest port based on size of the group. The only port that experienced an increase between 2010 and 2020 is the Port of Moerdijk, even though the increase is very small. For all ports combined, there is an decrease of 0.06 tonnes between 2010 and 2020, representing a reduction of about 7.5%. Table 17 displays the sulphur hexafluoride emissions for each sector. The table shows that the emissions of sulphur hexafluoride emissions occur almost exclusively in the 'other industry' sector, which includes the electrical industry.

Table 17 - Main sources of SF_6 emissions in port areas

Kton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	0.03
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	0.02	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.80	0.75	0.71	0.71
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.80**	**0.75**	**0.73**	**0.74**

Figure 6 shows the sulphur hexafluoride emissions for each analysed Dutch port area relative to the added value. It makes sense that the Port of Amsterdam is by far the highest, having the third highest added value of all ports, but also having very high sulphur hexafluoride emissions compared to other ports, being the second highest after the Port of Rotterdam. The Port of Rotterdam and Groningen Seaports have similar relative SF_6 emissions, after Groningen Seaports saw a significant increase between 2019 and 2020. The Port of Moerdijk and North Sea Port (Dutch part) have remained stable over the years, both having the lowest relative SF_6 emissions of the ports.

Figure 7 - SF_6 emissions in port areas in the Netherlands relative to added value



Carbon dioxide equivalent

Carbon dioxide equivalent (CO_2-eq.) is a unit of measurement that uses the climate effects of multiple greenhouse gases and standardises them to calculate the global warming potential. This formula takes into account the different global warming potentials for each GHG. For this calculation, we have used carbon dioxide (CO_2, GWP of 1), methane (CH_4, GWP of 25), nitrous oxide (N_2O, GWP of 298) and sulphur hexafluoride (SF_6, GWP of 22,800), as reported by Statistics Netherlands (CBS, 2019). Table 18 displays the carbon dioxide equivalents for all Dutch ports for the years 2010, 2015, 2019 and 2020, plus the totals for each year. At least 99% of the GWP for all Dutch port areas that are taken into account consist of CO_2 emissions.

Table 18 - CO_2-eq. emissions in port areas of selected Dutch ports

Kton CO_2-eq.	2010	2015	2019	2020
Amsterdam	4,563	6,021	5,004	2,876
Groningen	7,352	10,542	12,404	9,450
Moerdijk	5,288	3,895	4,966	4,823
Rotterdam	29,139	32,175	28,843	27,000
North Sea Port -NL	14,038	11,424	9,746	10,390
North Sea Port -BE	n/a	n/a	12,800*	11,111*
North Sea Port	n/a	n/a	22,546*	21,501*
Total	**60,380**	**65,317**	**62,162**	**55,523**

* These figures are based on the CO_2 emissions for the Belgium part of North Sea Port, as CO_2-eq. emissions in ports accounts for about 99% of CO_2 emissions.

Since 2015, a downward trend is visible for the total carbon dioxide equivalent. For all ports, the CO_2-eq. decreased between 2010 until 2020, except for Groningen Seaports. The emissions correspond to the sizes of each port, as the smaller ports have a smaller global warming potential. When looking at relative decrease of emissions, it is clear that the Port of Amsterdam experienced the largest decrease (-50.2%) between 2010 and 2020, followed by the Dutch part of the North Sea Port (-29.9%), the Port of Rotterdam (-13.3%), the Port of Moerdijk (-11.8%) and lastly Groningen Seaports (+28.2%). The reasons behind these changes are often the opening or closing of industrial facilities or power stations, as will be discussed in Section 4.3. Table 19 displays the most important sources of CO_2-eq. emissions within all port areas combined.

Table 19 - Main sources of CO_2-eq. emissions in total port areas in Netherlands

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	536	28	30	30
Chemical industry	11,615	10,825	11,938	13,179
Construction	65	19	16	23
Consumers	1,795	230	224	138
Drinking water supply	1	0	0	0
Energy sector	26,190	33,343	28,027	20,997
Mobility and transport	3,364	2,165	2,334	2,584
Nature	0	0	0	0
Other industry	1,634	1,088	1,029	979
Refineries	9,995	11,178	11,472	10,439
Sewage treatment	58	73	86	87
Trade, services and government	1,036	525	974	854
Waste disposal	4,090	4,583	4,833	5,229
Total	**60,380**	**64,057**	**60,964**	**54,539**

The three sector with the largest emissions are the energy sector, chemical industry and refineries. The energy sector saw quite significant decrease between 2010 and 2020 (-20%). The chemical industry saw an increase within this timeframe (+13.5%), and refineries remained around the same level (+4.4%). In the Port of Amsterdam, 45.9% of GWP emissions are caused by the ‘waste disposal’ sector. This is quite significant, as the second highest emitter, the ‘energy sector’, causes 29% of the GWP emissions within the port area. For Groningen Seaports, this is even more skewed: the ‘energy sector’ is by far the GWP emitter (68.7%) and the chemical industry is the second highest (10%). For the Port of Moerdijk, the largest emitting sector is the ‘chemical industry’, which accounts for 51.2% of all GWP emissions. The second highest emitting sector is ‘waste disposal’, which accounts for 26.9% of all GWP emissions within the Moerdijk port area. For the Port of Rotterdam, the ‘energy sector’ is the highest emitting sector with 36.7% of all GWP emissions. ‘Refineries’ are the second highest emitting sector, accounting for 34% of all GWP emissions within the port area. For the Dutch part of the North Sea Port, the ‘chemical industry’ causes the most GWP emissions (64.6%). The ‘energy sector’ is the second largest emitting sector, accounting for 16.8% of all GWP emissions, which is a significant difference.

4.3 International ports

The Netherlands has a good system for measuring GHG emissions, Emissieregistratie. Similar systems are often not available for international ports, which means that they have to calculate GHG emissions themselves. An exception are the large emitters in Europe: they have to report their environmental impact in an annual report. In this section, we start with the emissions reported by the ports. We then look at the emissions reported by large emitters at the ports in Europe.

GHG emissions are available for a selection of ports. The scope of the collected data varies. Many port authorities only measure their industrial emissions and do not report emissions for the entire port area. As shown in Paragraph 4.1, industrial sources are among the most important sources of carbon emissions in port areas. Table 20 displays an overview of the total emissions for various port areas. The ports of Bremen, Hamburg, Le Havre and London do not report CO_2 emissions. The Port of Antwerp, which houses an industrial complex, has significantly higher emissions compared to the other ports. In Long Beach and Los Angeles, emissions increased in 2021 compared to previous years. This is a consequence of the COVID-19 pandemic, which led to inefficiencies in transport. This included restrictions on the use of certain infrastructure, such as shore power, and container blockages.

Table 20 - Annual total CO_2 emissions (kton) in port areas

	2019	2020	2021
Antwerp	16,000	15,900	16,200
Barcelona	n/a	315	n/a
Long Beach	806	878	1,189
Los Angeles	880	899	1,253
Vancouver	n/a	1,190	n/a

A large number of international ports do not report GHG emissions for the entire port area. The relevant port authorities often do measure GHG emissions of their own industries. This includes the ports of Bremen, Hamburg, Le Havre and London. We will not present these results as these emission figures from port authorities are very small compared to total GHG emissions in port areas.

Large emitters

As mentioned in the previous section, large industrial areas are often located in port areas in Europe. These industrial areas often house large companies that are required to report emissions to national authorities and the European Union[4]. For each of the ports, we have collected the emission figures for large emitters within the port boundaries. The resulting CO_2 figures are shown in Table 10. Rotterdam, North Sea port (Dutch part) and Antwerp have the highest emissions of the selected ports. All these ports are known for their industrial complexes. Barcelona has the lowest emissions as it does not house a large industrial complex.

Our analysis shows that CO_2 emissions in port areas are mainly due to energy production and the chemical industry. Annual fluctuations are often due to production increases or decreases from a single facility. The most noteworthy are the following:

- Several power stations have been closed. In Amsterdam, the Hemweg Centrale closed[5] in 2020, resulting in a decrease in emissions of 2 Mton. In Le Havre[6], the power station closed in 2021 after a longer period of declining production. In London, a power station was closed in 2013[7]. In Rotterdam in 2017 two older power stations closed down, while in 2015 and 2016 new power stations had opened.
- In Germany, two power stations opened recently. A coal-powered station opened in Hamburg in 2015, which produced energy and heat. However, this station closed prematurely in 2020[8]. Two power stations were also opened in Groningen in 2013 and 2015, increasing emissions.
- Annual fluctuations are often due to specific circumstances. In Rotterdam, a malfunction at a power station reduced emissions in 2020 (DCMR Milieudienst Rijnmond, 2021). Between 2015 and 2017 new and old energy station run next to each other resulting in higher emissions for these years.
- In all countries, the demand for energy decreased due to the effects of the COVID-19 pandemic.

Results for a selection of large emitters in the Netherlands shows that emissions from industry between 2022 and 2021 reduced with 8.3% according to (Dutch Emissions Authority, 2023). Experts suggest that this reductions is a consequence of lower production due to rising energy prices in response of the war in Ukraine and not necessarily due to increased sustainability. It is not clear what the long term consequences is are when energy prices stabilise again.

Table 21 – Annual CO_2-eq. emissions from large emitters in port areas

Kton	2010	2015	2016	2017	2018	2019	2020
Amsterdam	3,647	5,397	5,691	4,931	5,113	4,321	2,198
Antwerpen	15,963	14,799	14,357	14,782	14,676	14,624	14,342
Barcelona	6	878	763	648	845	1,024	169
Bremen ports*	7,306	7,609	6,854	9,410	n/a	n/a	n/a
Hamburg*	4,307	7,977	8,742	9,116	n/a	n/a	n/a

4 https://ec.europa.eu/environment/industry/stationary/e-prtr/legislation.html
5 https://nos.nl/artikel/2315981-hemwegcentrale-officieel-gesloten-nog-vier-kolencentrales-over
6 www.edf.fr/en/the-edf-group/taking-action-as-a-responsible-company/corporate-social-responsibility/doing-even-more-to-reduce-co2-emissions
7 https://en.wikipedia.org/wiki/Tilbury_power_stations
8 https://nl.wikipedia.org/wiki/Elektriciteitscentrale_Hamburg-Moorburg

Kton	2010	2015	2016	2017	2018	2019	2020
Le Havre	9,349	6,153	7,057	6,551	5,697	4,439	3,957
London*	10,984	3,695	4,946	4,269	4,285	4,220	n/a
Groningen	7,035	10,214	13,631	13,022	13,265	12,209	9,252
North Sea	24,914	24,257	23,355	23,812	23,539	23,436	21,156
Moerdijk	5,116	3,699	5,082	5,754	4,819	4,808	4,662
Rotterdam	26,194	29,373	31,107	28,813	26,882	26,225	24,125

* Last three years for Germany not available, 2020 not available for United Kingdom.

4.4 Conclusions greenhouse gas emissions

Reducing GHG emissions is a major challenge for ports. The importance of reducing emissions has been recognised by the ports and emissions reduction occur at several ports. At some ports there is however no significant reduction is visible. The following results are visible:

- Hosting industrial facilities in the port has a large impact on GHG emissions in port areas. A handful of companies can be responsible for over 90% of the emissions. Emissions related to transhipment and transport are small compared to emissions from industrial facilities.
- With a few exceptions, emissions from industrial facilities at European ports have not shown large decreases between 2010 and 2020.
- Due to the COVID-19 pandemic emissions in 2020 from energy production where lower compared to 2019.
- Early results of 2021 and 2022 show reductions from industrial facilities in the Netherlands. These reductions are mainly a consequence of fewer production due to high energy prices in consequence of the war in Ukraine. Coming years should show whether this will result in increased sustainability or a shift of production to other countries. For industry to become sustainable remains a large undertaking.
- Not all ports monitor and publish carbon emissions. Some ports, such as London, only report emissions from the port authority or for a limited scope.

5 Air pollutants

In this chapter, the emissions that affect air quality in the ports and the concentrations of air quality pollutants are discussed. We discuss air quality by type of pollutant. We start with the concentrations and emissions of nitrogen oxide, followed by particulate matter ($PM_{2.5}$ and PM_{10}) and sulphur oxide. Emissions of other substances, such as ammonia, benzopyrene and carbon monoxide, are discussed last.

5.1 Nitrogen oxides

During fuel combustion at high temperatures, nitrogen atoms in the air combine with oxygen atoms to form nitric oxide (NO). In normal concentrations, nitric oxide is relatively harmless. When nitric oxide further combines with oxygen (O_2) and ozone (O_3), it forms nitrogen dioxide (NO_3), which is harmful to human health. Nitrogen dioxide is an irritant gas, which at high concentrations leads to inflammation of the airways. Prolonged exposure can damage the functioning of the lungs, increase the risk of respiratory conditions and intensify the response to allergens. Nitrogen oxides can also lead to higher levels of fine particulate matter (PM) and ground-level ozone, which can also have harmful effects on human health. The ecological effect of nitrogen oxides is the formation of acid rain, which can damage buildings and natural ecosystems due to acid deposition.

Dutch ports

Car engines or lightning (natural source) cause combustion in the presence of nitrogen, leading to the formation of NO_x. According to the Dutch RIVM, nitrous oxides in the Netherlands are mainly emitted by traffic, power plants and industry (RIVM, n.d.). Table 22 displays the NO_x emissions for all Dutch ports over the years 2010, 2015, 2019 and 2020. 2015, 2019 and 2020 are at the level of 1x1 kg squares, but because this scope was not available for 2010, 5x5 kg squares have been used, multiplied by the average difference for all other years for each port to minimise overestimation.

The Port of Rotterdam has the highest emissions, followed by the North Sea Port (Dutch part), which are the largest ports studied. The port with the third highest NO_x emissions is the Port of Amsterdam, which is the smallest port based on size. Groningen Seaports and the Port of Moerdijk are the lowest NO_x emitting ports. Between 2010 and 2015, there is a large difference in emissions, which can be partially explained by the broader scope of 2010 emissions due to 5x5 km squares. Between 2010 and 2020, there is a small but steady decrease over the years. The Port of Moerdijk is the port with the lowest NO_x emissions overall. Groningen Seaports had the largest relative decrease.

Table 22 – NO_x emissions in port areas of selected Dutch ports

Kton NO_x	2010	2015	2019	2020
Amsterdam	4.23	4.20	4.59	3.92
Groningen	4.03	4.01	4.15	3.25
Moerdijk	3.96	2.44	2.67	2.72
Rotterdam	28.67	25.80	24.00	25.13
North Sea Port -NL	8.38	7.48	7.66	7.43
North Sea Port -BE	n/a	n/a	n/a	n/a

Kton NO_x	2010	2015	2019	2020
North Sea Port	n/a	n/a	n/a	n/a
Total	**49.27**	**43.93**	**43.07**	**42.45**

Table 23 shows the nitrogen oxide emissions of all Dutch ports studied by sector. The largest sector in terms of emissions is mobility and transport, which is comparable to the largest emitting sector for the Netherlands according to RIVM. The second largest sector emitting NO_x is the energy sector, which is 3.75 times smaller than the mobility and transport sector. The Port of Rotterdam has by far the highest NO_x emissions, which can be explained by maritime vessels emitting high levels of NO_x. In a port as large as Rotterdam with so much throughput, the emissions from mobility and transport will be especially large, as can be seen in Annex B. The table shows that refineries (4 kton) and the energy sector (2.90 kton) also play a role in the high NO_x figure. Almost all sectors experienced decreased emissions between 2015 and 2020, except for mobility and transport, the chemical industry and trade, services and government.

Table 23 - NO_x emissions in port areas in the Netherlands by sector

Kton NO_x	2010	2015	2019	2020
Agriculture	1.12	0.11	0.09	0.09
Chemical industry	6.01	5.15	5.43	5.59
Construction	0.04	0.01	0.01	0.01
Consumers	0.87	0.10	0.08	0.05
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	9.57	9.92	8.10	6.10
Mobility and transport	23.38	19.49	20.57	22.92
Nature	0.01	0.00	0.00	0.00
Other industry	1.49	1.52	1.28	0.92
Refineries	4.58	5.19	5.24	4.45
Sewage treatment	0.03	0.04	0.05	0.04
Trade, services and government	0.58	0.23	0.29	0.30
Waste disposal	1.61	2.15	1.93	1.97
Total	**49.27**	**43.93**	**43.07**	**42.45**

Figure 7 shows the relative NO_x emissions compared to the added value. The Dutch part of the North Sea Port is the port with the highest relative NO_x emissions, having surpassed both the Port of Moerdijk and Groningen Seaports between 2019 and 2020. Moerdijk and Groningen are the only ports that experienced an increase between 2015 and 2020.
The Port of Amsterdam and the Port of Rotterdam have the lowest relative NO_x emissions of the Dutch ports, with very similar emissions in 2020. The high emissions in 2010 can partly be explained by the broader scope leading to an overestimation.

Figure 8 - NO_x emissions in port areas in the Netherlands relative to added value

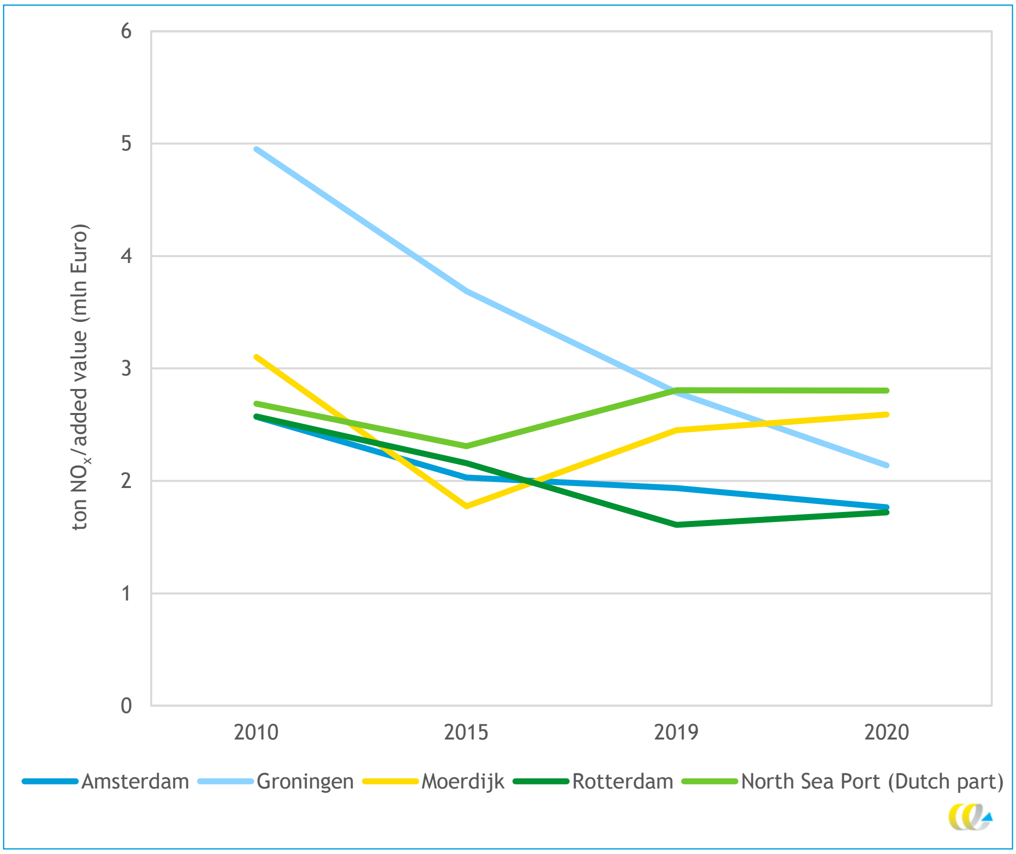


Figure 8 shows the NO_x emissions relative to the size of the ports. The ports of Rotterdam and Amsterdam have the highest NO_x emissions per square km. The Port of Moerdijk has the lowest NO_x emissions per square km and Groningen Seaports has slightly higher emissions per square km.

Figure 9 - NO_x emissions in port areas in the Netherlands relative to size (square kilometre)

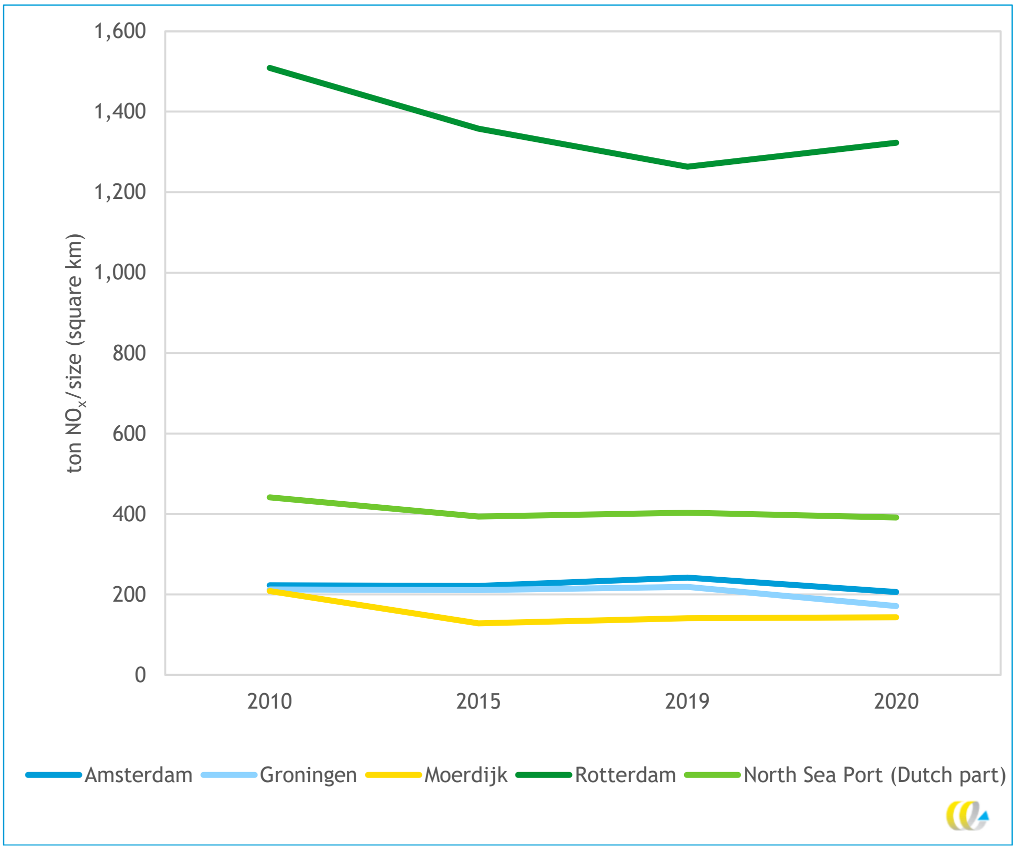
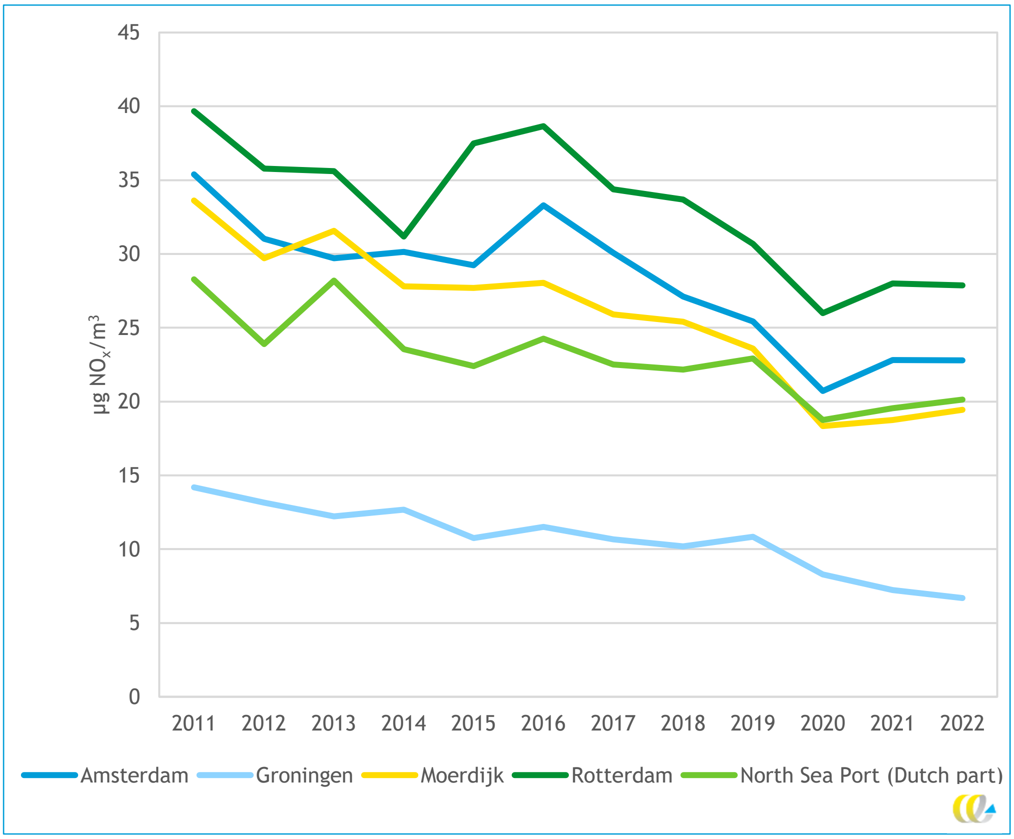


Figure 9 shows the NO_x concentration for each port area from 2011 to 2022. All port areas have experienced a decrease in concentration within this timeframe. The Port of Rotterdam has the highest concentration per m^3 over the entire period. The Port of Amsterdam has the second highest concentration, followed by North Sea Port (Dutch part), which overtook the Port of Moerdijk in 2020. The Port of Groningen has the lowest concentration of NO_x per m^3.

Figure 10 - Average NO_x concentration in port areas in the Netherlands



International ports

Nitrogen oxides are also calculated and monitored in several international ports. The Port of Le Havre only measures emissions of fine particles from shipping while the Port of London and Hamburg authorities only include emissions from their operations. The results are not included in the tables due to this difference in scope. The emission levels are displayed in Table 24. The results show that emissions have remained fairly stable in recent years.
The ports of Long Beach and Los Angeles even show increases in emissions. These increases are a consequence of the COVID-19 pandemic, which restricted the use of shore power. Due to limits in data availability and quality we have not made graphs relative to added value.

Table 24 - Emissions of nitrous oxides (kton) in port areas

	2010	2015	2019	2020	2021
Antwerp	38	32	29	25	26
Barcelona	n/a	n/a	n/a	6.2	n/a
Long Beach	n/a	n/a	7	6	8
Los Angeles	n/a	n/a	6	6	9
Vancouver	n/a	13	n/a	11	n/a

Table 25 shows the concentration of nitrous oxides in various port areas. The concentration shows a slow reduction trend in recent years. The concentrations in ports are monitored more often compared to the emissions.

Table 25 – Annual average concentration of nitrous oxides (mg/m^3) in port areas

	2010	2015	2019	2020	2021
Antwerp	38	32	31	29	25
Barcelona	n/a	n/a	41	32	n/a
Bremen	n/a	n/a	13	11	12
Bremerhaven	n/a	n/a	20	18	19
Hamburg	n/a	n/a	31	27	27
Long Beach	n/a	n/a	33	31	29
Los Angeles	38	32	22	24	24
Vancouver	n/a	n/a	14	11	13

5.2 Particulate matter

Particulate matter (PM) are a mixture of (microscopic) solid particles and liquid matter in the air. Some particles can be seen with the naked eye, such as dust, dirt, soot or smoke. Other particles are so small that they can only be seen using an electron microscope. Primary particulate matter arises due to combustion, friction or evaporation. Secondary particulate matter arises through complex reactions of chemicals.

Particulate matter is emitted by natural or human sources. Natural sources include volcanic eruptions, windblown dust and oceans (sea salt). Human sources include the burning of fossil fuels, biomass, transport wear and tear, power plants, livestock farms and open fires (barbecues). According to the ministry Of Infrastructure And Water Management, natural sources of particulate matter play a slightly larger role than human sources. Among human sources, the main emitters are traffic (road and water, mainly diesel, around 40%), industry (slightly lower than traffic) and agriculture (23%) (Rijkswaterstaat, n.d.).

Particulate matter is often categorised as either $PM_{2.5}$ or PM_{10}. PM_{10} are inhalable particles that have a diameter of 10 micrometres or less. $PM_{2.5}$ are fine inhalable particles that have a diameter of 2.5 micrometres or smaller. Both types of particulate matter are not visible to the naked eye. Particulate matter contains microscopic solids or liquid droplets small enough to be inhaled and cause health issues. Particles less than 10 micrometres in diameter can get deep into the lungs, and some may possibly get into the bloodstream. Particles with a diameter of less than 2.5 micrometres in diameter can cause even greater health risks. Particles less than 0.5 micrometres are even more dangerous, but are difficult to measure. Soot, which consists of particulate matter, can cause smog, dirty buildings and pollute nature.

Dutch ports

Table 26 shows the $PM_{2.5}$ emissions at Dutch ports and Table 27 shows the PM_{10} emissions. Emissieregistratie provides the data at the level of 5x5 km squares, except for PM_{10}, for the years 2015, 2019 and 2020. The emissions or both types of particulate matter decreased between 2010 and 2020. $PM_{2.5}$ levels decreased by about 39% between 2010 and 2020, and PM_{10} levels decreased by about 52% within this timeframe. For both types of particulate matter, the Port of Rotterdam is the largest emitter, followed by the Dutch part of the North Sea Port, the Port of Amsterdam, the Port of Moerdijk and Groningen Seaports. Because Groningen Seaports and the Port of Moerdijk are quite similar in size, it comes as no surprise that their emissions are very similar as well. The Port of Amsterdam has high PM emissions relative to its size. All ports experienced a decrease in PM between 2010 and 2020, but Groningen Seaports has the lowest relative decrease. The total PM_{10} emissions in the Netherlands in 2020 were 27.2 kton (CBS, 2022b). Port emissions contribute around 9.2% to the national total.

Table 26 - $PM_{2.5}$ emissions in port areas of selected Dutch ports

Kton $PM_{2.5}$	2010	2015	2019	2020
Amsterdam	0.49	0.45	0.39	0.33
Groningen	0.12	0.12	0.16	0.09
Moerdijk	0.22	0.09	0.10	0.11
Rotterdam	1.51	1.32	1.10	1.06
North Sea Port -NL	1.00	0.72	0.55	0.44
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**3.34**	**2.71**	**2.29**	**2.03**

Table 27 - PM_{10} emissions in port areas of selected Dutch ports

Kton PM_{10}	2010	2015	2019	2020
Amsterdam	0.48	0.52	0.42	0.38
Groningen	0.15	0.15	0.20	0.11
Moerdijk	0.23	0.09	0.10	0.11
Rotterdam	2.13	1.73	1.45	1.42
North Sea Port -NL	1.02	0.87	0.61	0.48
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**4.02**	**3.36**	**2.78**	**2.50**

Table 28 shows which sectors emit the most $PM_{2.5}$ emissions and Table 29 shows which sectors emit the most PM_{10} emissions. $PM_{2.5}$ is at 5x5 km squares level and PM_{10} is at 1x1 squares level, except for 2010, which is at 5x5 km squares level due to it not being available at 1x1 km squares level. The outcomes of the 5x5 data have been multiplied by the average difference between the 5x5 and 1x1 data for each port. The largest source of $PM_{2.5}$ emissions is mobility and transport, with consumers being the second highest emitter and the chemical industry (primarily located in North Sea Port) being in third place. The largest source of PM_{10} emissions is trade, services and government, with mobility and transport in second place. Especially in the ports of Rotterdam and Amsterdam, trade, services and government is a significant source (0.51 and 0.17, respectively).

Table 28 - $PM_{2.5}$ emissions in port areas in the Netherlands by sector

Kton $PM_{2.5}$	2010	2015	2019	2020
Agriculture	0.01	0.01	0.01	0.01
Chemical industry	0.70	0.53	0.42	0.31
Construction	0.04	0.04	0.04	0.04
Consumers	0.57	0.39	0.38	0.32
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.08	0.15	0.06	0.03
Mobility and transport	1.16	0.87	0.77	0.78
Nature	-	-	-	-
Other industry	0.42	0.31	0.27	0.22
Refineries	0.21	0.23	0.18	0.15

Kton $PM_{2.5}$	2010	2015	2019	2020
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.13	0.14	0.14	0.13
Waste disposal	0.03	0.04	0.03	0.03
Total	**3.34**	**2.71**	**2.29**	**2.03**

Table 29 – PM_{10} emissions in port areas in the Netherlands by sector

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.03	0.01	0.01	0.01
Chemical industry	0.74	0.72	0.51	0.39
Construction	0.08	0.02	0.02	0.02
Consumers	0.48	0.08	0.09	0.07
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.08	0.22	0.08	0.03
Mobility and transport	1.06	0.64	0.61	0.65
Nature	-	-	-	-
Other industry	0.69	0.50	0.43	0.36
Refineries	0.24	0.27	0.22	0.19
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.61	0.85	0.78	0.73
Waste disposal	0.02	0.05	0.04	0.04
Total	**4.02**	**3.36**	**2.78**	**2.50**

Figure 10 shows the results for $PM_{2.5}$ relative to the added value of each port. Figure 11 shows the results for PM_{10} relative to the added value of each port. For both types of particulate matter, the Dutch part of the North Sea Port has the highest relative values of all ports, followed by the Port of Amsterdam, the Port of Moerdijk, the Port of Rotterdam and Groningen Seaports. The top two ports could be expected based on particulate matter emissions, as the Dutch part of the North Sea Port houses a large industry complex, while the Port of Amsterdam tranships large quantities of bulk goods, such as coal. Emissions fell at all ports between 2010 and 2020. However, the Port of Moerdijk experienced an increase for both types of particulate matter between 2015 and 2020, after a sharp decline between 2010 and 2015. According to Emissieregistratie, this increase is mainly due to the chemical industry located here.

Figure 11 - $PM_{2.5}$ emissions in port areas in the Netherlands relative to added value

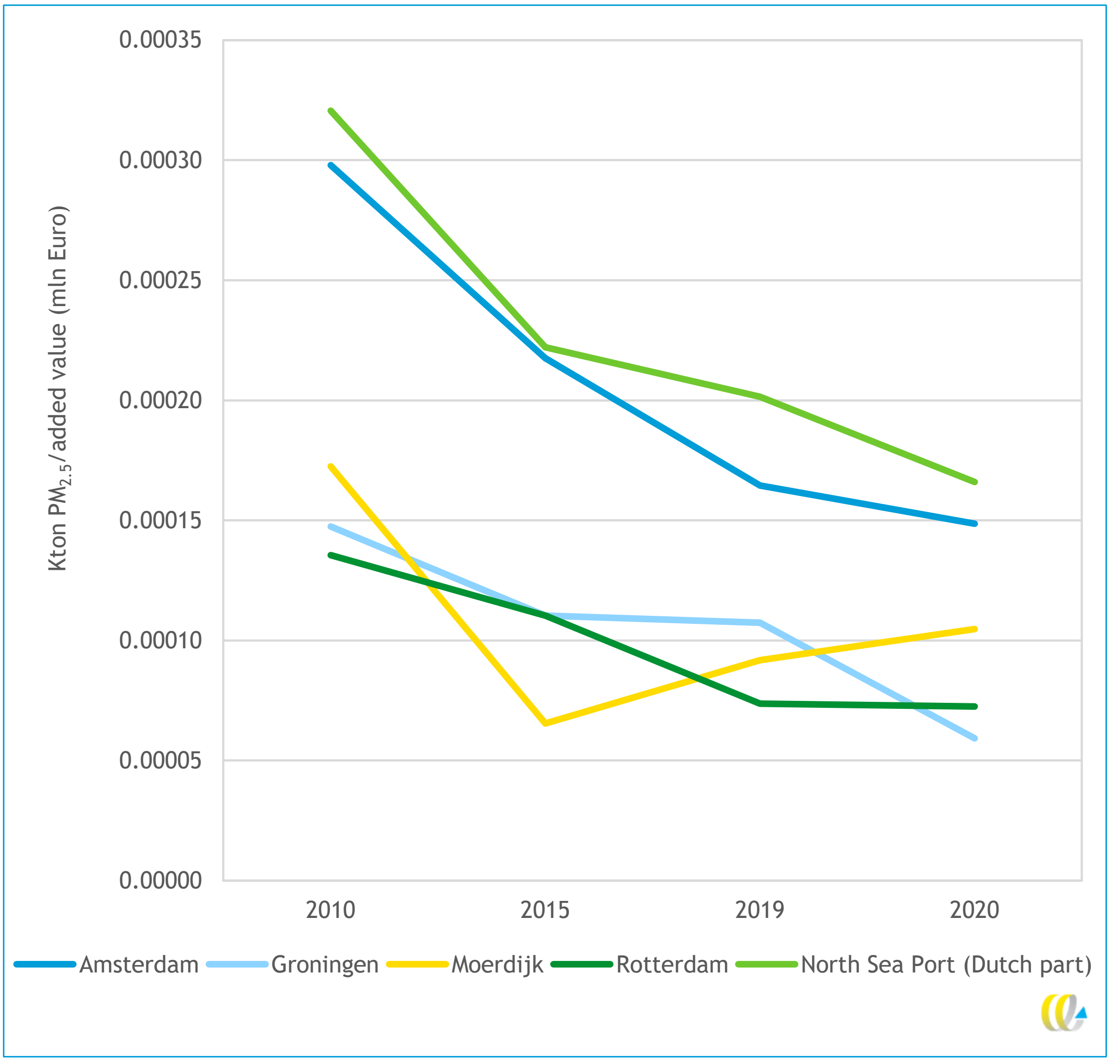


Figure 12 - PM_{10} emissions in port areas in the Netherlands relative to added value

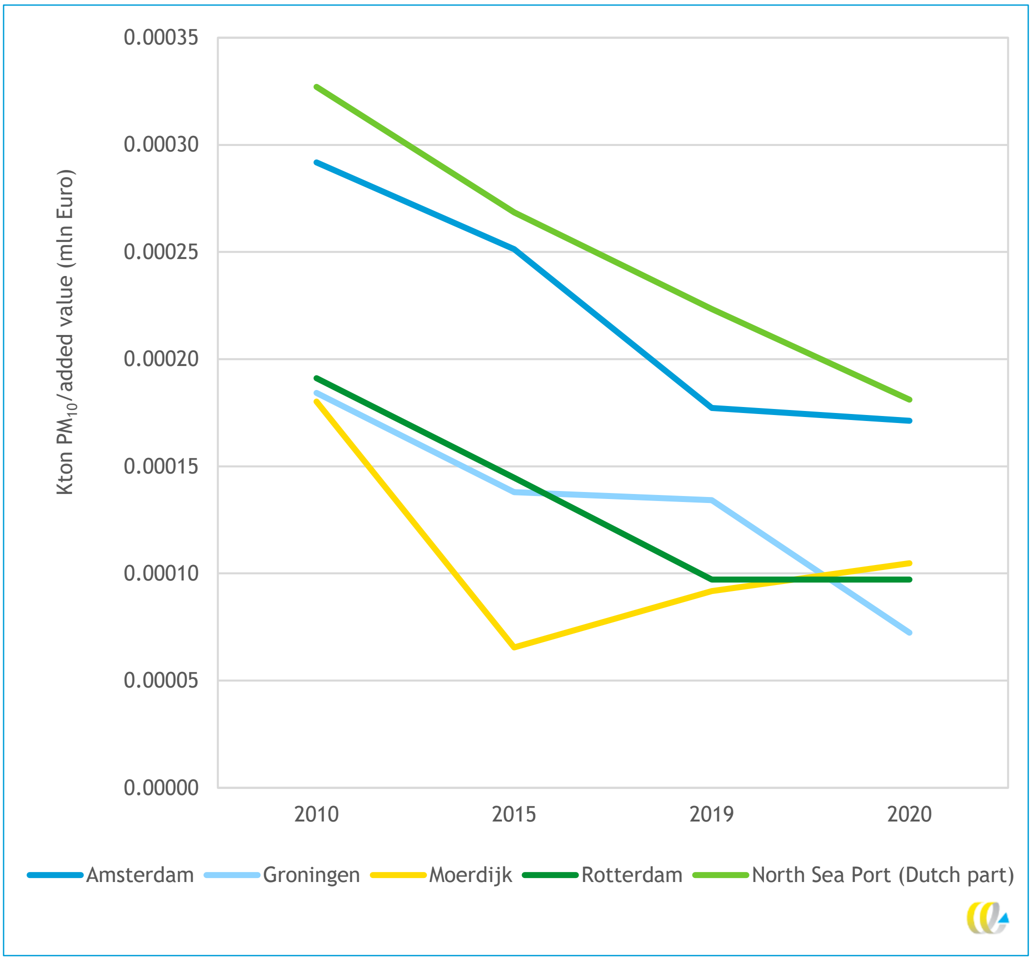


Figure 12 and Figure 13 show the average concentration of $PM_{2.5}$ and PM_{10} in the port areas. All ports experienced a decrease in concentration of $PM_{2.5}$ and PM_{10} between 2010 and 2020. The Port of Amsterdam has the highest concentration, followed by the Port of Rotterdam and the Port of Moerdijk. The Port of Groningen and the Dutch part of the North Sea Port have the lowest concentration of particle matter and the differences between the two ports is very small. PM_{10} concentrations show a less steep decrease than the $PM_{2.5}$ decrease.

Figure 13 - Average $PM_{2.5}$ concentration in port areas in the Netherlands

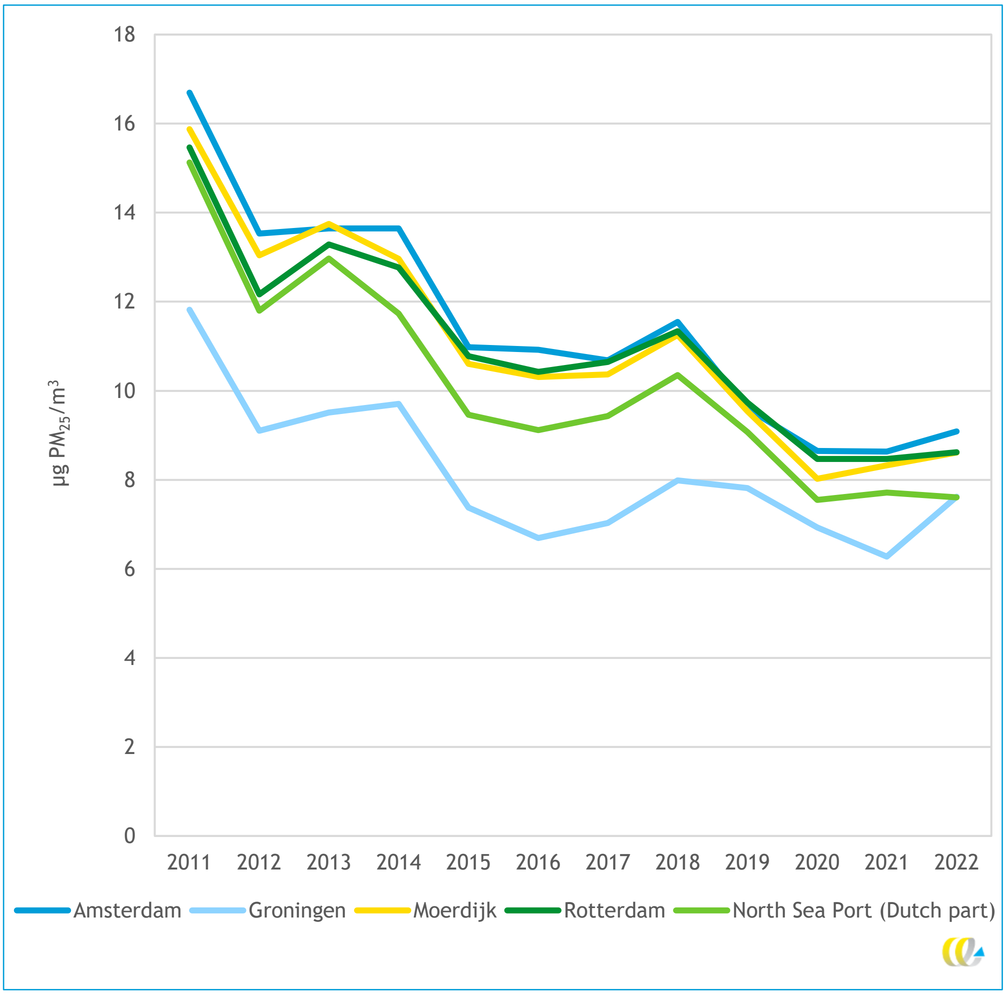
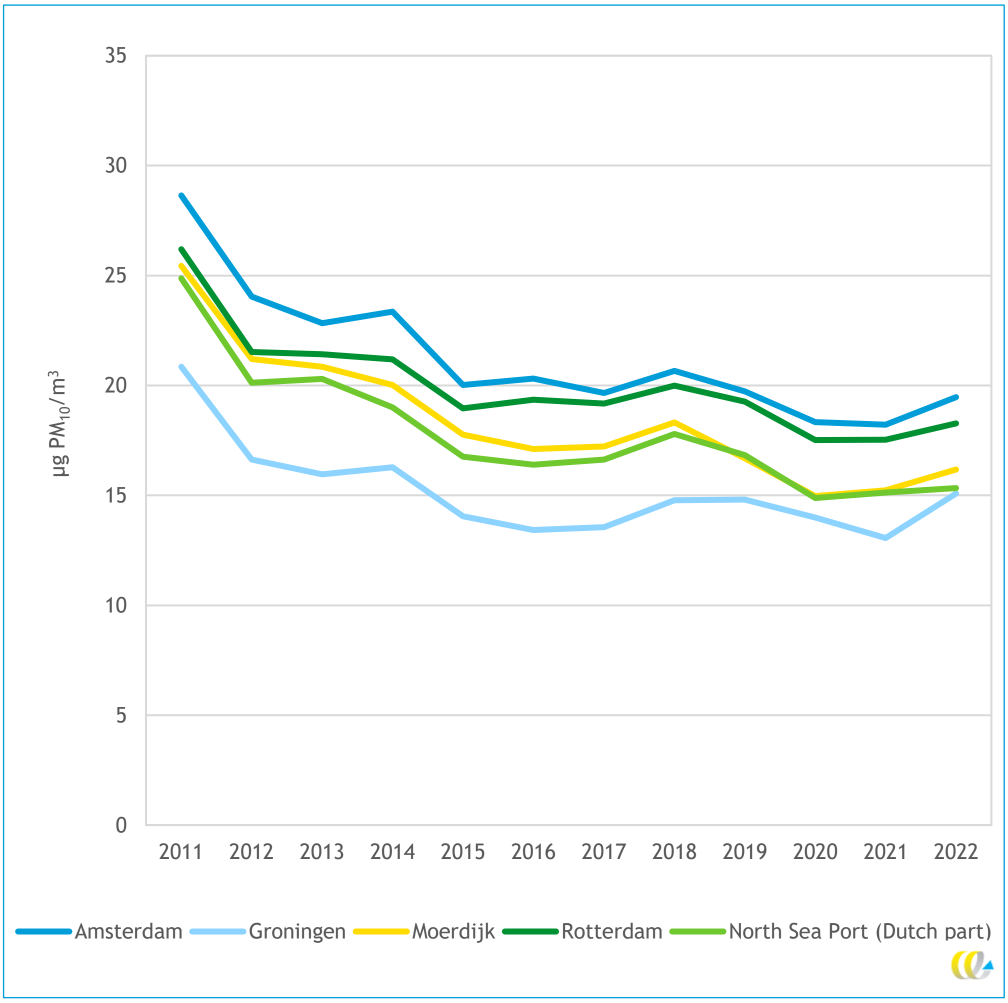


Figure 14 - Average PM_{10} concentration in port areas in the Netherlands



International ports

Emissions of particulate matter are monitored in a number of international ports. Table 30 shows the emissions of particles below 2.5 mm, while Table 31 shows the emissions of particles below 10 mm. The Port of Le Havre only measures emissions of fine particles from shipping while the Port of London and Hamburg authorities only include emissions from their operations. The results are not included in the tables due to this difference in scope. Due to the COVID-19 pandemic the use of shore-power in Long Beach and Los Angeles was considerably lower. As a result the emissions increased in 2020 and 2021. Due to limits in data availability and quality we have not made graphs relative to added value.

Table 30 - Emissions of $PM_{2,5}$ in port areas

kton	2010	2015	2019	2020	2021
Antwerp	0.8	0.7	n/a	0.7	0.7
Long Beach	n/a	n/a	0,13	0,10	0,16
Los Angeles	n/a	n/a	0,12	0,11	0,17
Vancouver	n/a	0,288	n/a	0,257	n/a

Table 31 - Emissions of PM_{10} in port areas

kton	2010	2015	2019	2020	2021
Antwerp	1,2	1,0	n/a	1,1	1,1
Long Beach	n/a	n/a	0,14	0,11	0,17
Los Angeles	n/a	n/a	0,13	0,12	0,18

The concentration of air quality is monitored at a slightly larger selection of ports. Table 32 shows the concentration of particles below 2.5 mm, while Table 33 shows the concentration of particles below 2.5 mm. In all ports the concentration of fine particles is improving.

Table 32 - Concentration of $PM_{2,5}$ in port areas

$PM_{2,5}$	2010	2015	2019	2020	2021
Antwerp	26	13	-	13	12
Bremen	n/a	n/a	11	9	9
Bremerhaven	n/a	n/a	18	15	15
Long Beach*	n/a	n/a	7.3 up to 9.5	9.8 up to 12.5	9.5 up to11.3
Los Angeles	n/a	n/a	5	8	5
Vancouver	n/a	n/a	7	7	6

* Long beach in ppm.

Table 33 - Concentration of PM_{10} in port areas

$PM_{2,5}$	2010	2015	2019	2020	2021
Antwerp	29	23	n/a	23	22
Barcelona	n/a	n/a	34,3	30,8	n/a
Bremen	n/a	n/a	19	17	17
Bremerhaven	n/a	n/a	18	15	15
Hamburg	n/a	n/a	18	18	18
Long Beach	n/a	n/a	21-37.4	26.4-38.1	22.9-32.1
Los Angeles	n/a	n/a	22	25	28
Vancouver	n/a	n/a	6,9	7,39	6,08

* Long beach in ppm, Vancouver in ppb.

5.3 Sulphur dioxide

Sulphur dioxide (SO_2) is a heavy, colourless gas that is harmful to human health. Natural sources of sulphur dioxide include volcanic gases combined with water, for example from warm springs. Human causes include the burning of fossil fuels, such as by power plants, certain industrial processes, as well as all kinds of mobility options.

Road transport causes a limited amount of sulphur due to using fuel with a low sulphur content. Maritime shipping and certain locomotives still use fuel with relatively high sulphur content. On January 1st 2020, a new reduced limit on sulphur in marine fuel oil was implemented, which aims to reduce total sulphur oxide emissions from shipping by about 70% (International Maritime Organization, 2021). According to CBS, the total SO_2 emissions in 2021 amounted to 22.9 Kton, which is slightly less than double the emissions of all ports combined (CBS, 2022a).

Dutch ports

Table 34 shows the SO_2 emissions of each port area. The largest port (Rotterdam) has the highest SO_2 emissions. Groningen Seaports has the second highest emissions and the Dutch part of the North Sea Port the third highest, which could be explained by the fact that Emissieregistratie only takes the emissions within the Netherlands into account. Moerdijk and Amsterdam, the smallest ports in size, have the lowest sulphur dioxide emissions of the ports.

Table 34 - SO_2 emissions in port areas of the selected Dutch ports

Kton SO_2	2010	2015	2019	2020
Amsterdam	0.69	0.99	0.55	0.16
Groningen	1.44	1.52	2.18	1.71
Moerdijk	0.56	0.22	0.27	0.34
Rotterdam	17.23	14.57	9.74	8.52
North Sea Port -NL	4.13	2.80	1.89	1.55
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**24.06**	**20.10**	**14.63**	**12.28**

Table 35 shows sulphur dioxide emissions per sector for all port areas combined. The highest emissions in port areas are caused by refineries (7.22 kton), followed by other industry (1.91 kton) and the chemical industry (1.35 kton). A steady decrease of SO_2 emissions is visible between 2010 and 2020, almost halving during this period.

Table 35 - SO_2 emissions in port areas in the Netherlands by sector

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	1.89	1.42	1.31	1.35
Construction	0.00	0.00	0.00	0.00
Consumers	0.04	0.00	0.00	0.00
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	3.29	4.96	1.56	0.81
Mobility and transport	3.22	0.81	0.81	0.83
Nature	-	-	-	-
Other industry	2.81	1.62	2.09	1.91
Refineries	12.60	11.12	8.71	7.22
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.02	0.03	0.04	0.03
Waste disposal	0.18	0.14	0.10	0.13
Total	**24.06**	**20.10**	**14.63**	**12.28**

Figure 14 shows the SO_2 emissions relative to the added value. Groningen Seaports has the highest relative SO_2 emissions. The Port of Amsterdam and Port of Rotterdam are very similar, because the relative SO_2 emissions of Rotterdam fell in previous years. The Port of Moerdijk has the second to lowest relative SO_2 emissions and the Port of Amsterdam has the lowest SO_2 emissions.

Figure 15 - SO_2 emissions in port areas in the Netherlands relative to added value

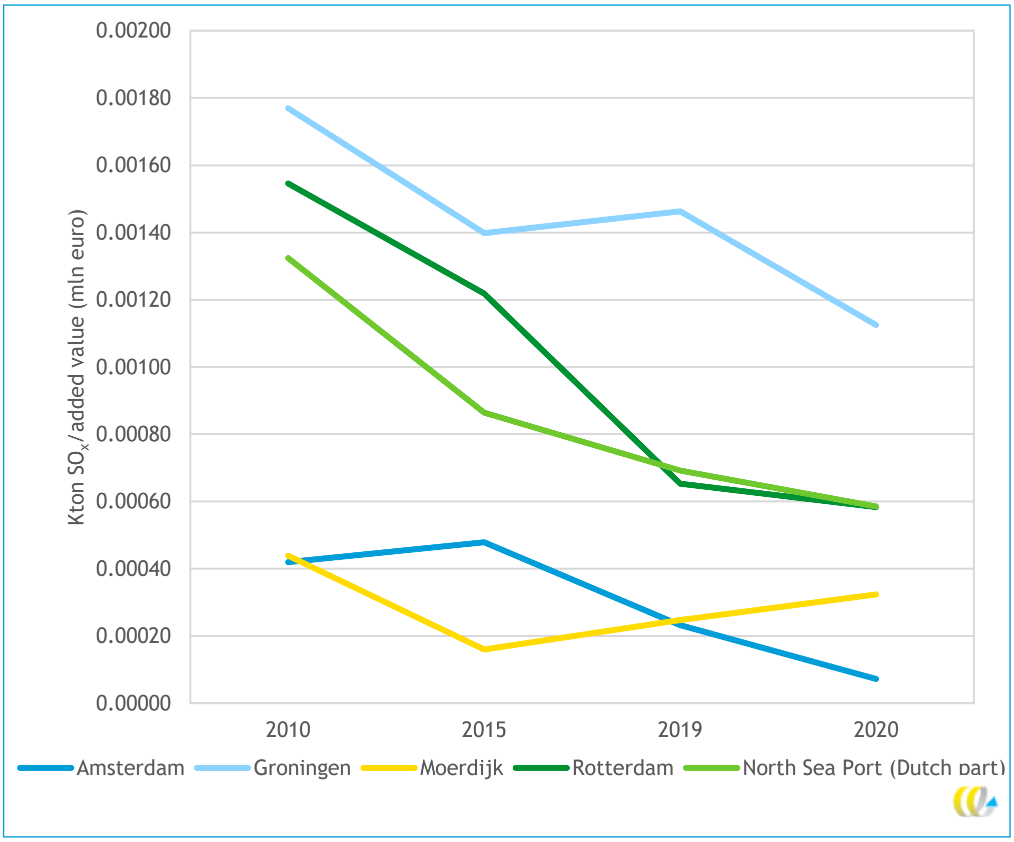
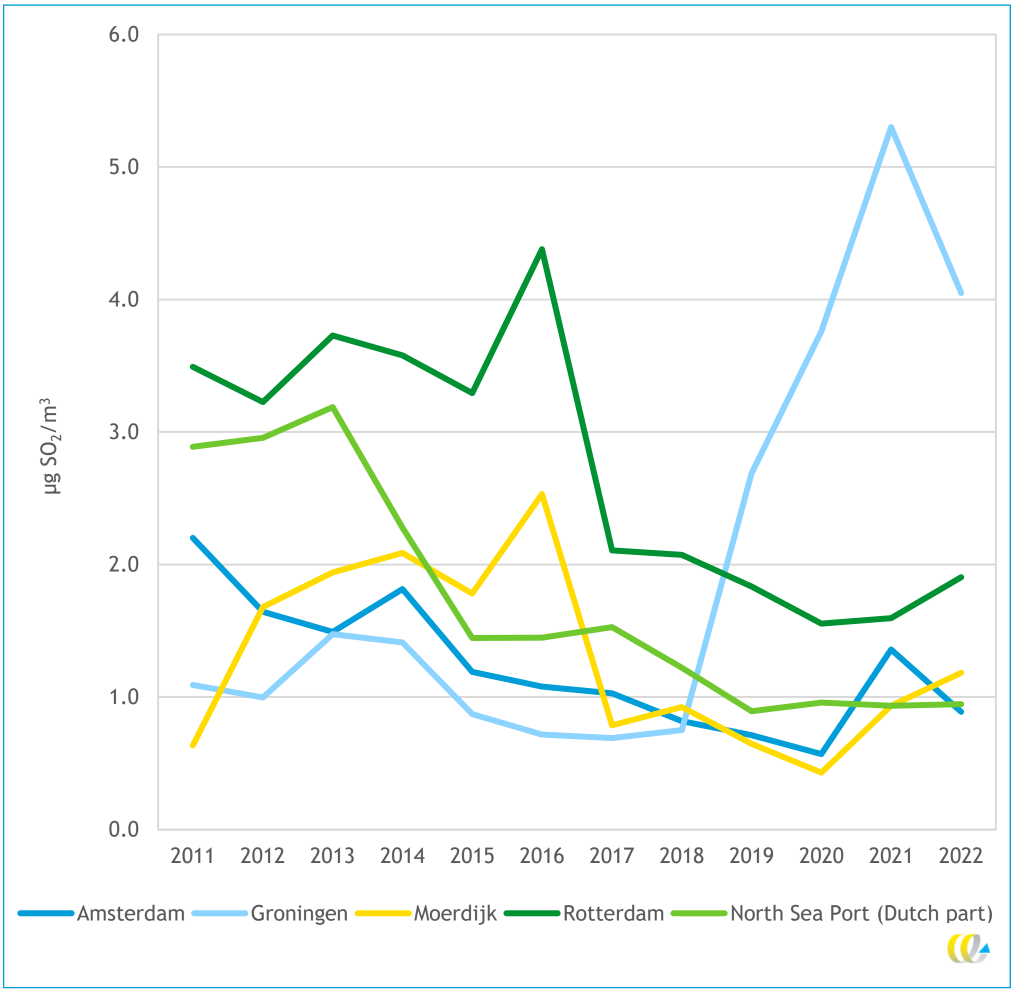


Figure 15 shows the average SO_2 concentration for the Dutch port areas for the period between 2011 and 2022. In general, most ports experienced a decrease of SO_2 emissions between 2011 and 2022, except for the Port of Groningen, which experienced a very steep increase around 2020-2021, which led to the port having the highest concentration of SO_2 of the Dutch ports. It is unclear what the precise source is for the increase in concentrations, but it seems to be related to increases in SO_2 emissions in the port (see Table 120). The Port of Rotterdam had the second highest concentration in 2022, followed by the Port of Moerdijk, the Dutch part of the North Sea Port and the Port of Amsterdam.

Figure 16 - Average SO_2 concentration in port areas in the Netherlands



International ports

Sulphur dioxide emissions are only measured in a small number of ports. The Port of Le Havre only measures emissions of fine particles from shipping while the Port of London and Hamburg authorities only include emissions from their operations. The results can be seen in Table 36. The ports of Long Beach And Los Angeles show an increase in emissions in 2021. This is a consequence of higher emissions from maritime shipping. Due to the COVID-19 pandemic, there was less use of shore power and the auxiliary engines of vessels had to be used.

Table 36 - Emissions of SO_2 in port areas

kton	2019	2020	2021
Antwerp	n/a	8.5	n/a
Long Beach	0.2	0.2	0.3
Los Angeles	0.1	0.1	0.3

The concentration of sulphur dioxide has been measured by several ports. The results are shown in Table 37. The concentrations are decreasing in most ports.

Table 37 - Concentration of SO_2 in port areas

kton	2010	2015	2019	2020	2021
Antwerp	6	4	5	4	4
Barcelona	n/a	n/a	2	1	n/a
Bremen	n/a	n/a	2	1	1
Bremerhaven	n/a	n/a	1	1	1
Hamburg	n/a	n/a	4	n/a	n/a
Long Beach	n/a	n/a	6	2	2
Vancouver	n/a	n/a	0.7	0.7	0.8

5.4 Other substances

5.4.1 Ammonia

Since 1990, ammonia (NH_3) emissions in the Netherlands have declined sharply. In 1990, emissions were 351.3 kton and in 2017, emissions were 132.4 kton, which is a decrease of 62.3% (Melkvee, 2019). Agriculture is the largest emitter of ammonia by far. It causes approximately 86% of NH_3 emissions according to Emissieregistratie. Other causes include fertilized natural areas, non-commercial agricultural activities, transport, households and industry. Ammonia can be harmful to human health in high concentrations. High concentrations of ammonia can also be harmful to the environment. In common with nitrogen oxides, it is a major contributor to acidification and ammonia can lead to eutrophication[9] due to manure pollution. Ecosystems can become disturbed, as vegetation that prospers on nitrogen-rich ground, such as grass and nettles, can displace and dominate other types of plants.

Table 38 displays ammonia emissions in Dutch ports for the years 2010, 2015, 2019 and 2020. The data are at the level of 1x1 km squares, which means that there may be an overestimation, mainly because agricultural areas just outside the port areas have been taken into account. The 2010 figures are based on 5x5 km squares level, multiplied by the average difference of NH_3 emissions between the 5x5 km squares level data and the 1x1 km squares level data.

Table 38 – NH_3 emissions in port areas of selected Dutch ports

Kton NH_3	2010	2015	2019	2020
Amsterdam	0.05	0.05	0.05	0.05
Groningen	0.07	0.08	0.08	0.08
Moerdijk	0.08	0.08	0.08	0.08
Rotterdam	0.25	0.22	0.24	0.26
North Sea Port -NL	0.54	0.56	0.39	0.44
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**0.99**	**0.99**	**0.84**	**0.92**

[9] Eutrophication is when a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of algae.

Total ammonia emissions remained fairly stable between 2010 and 2020. However, an increase is visible between 2019 and 2020. North Sea Port (Dutch part) has the highest NH_3 emissions, followed by the Port of Rotterdam, the Port of Moerdijk and Groningen Seaports, and lastly the Port of Amsterdam. According to Emissieregistratie, the high ammonia levels in the Dutch part of the North Sea Port are partially explained by a company in Zeeland, specialising in the production of fertilizers. Also, a large part of the ammonia emissions in the Dutch part of the North Sea Port are emitted by the agricultural sector, which may be due to the 5x5 km squares leading to a less precise demarcation of the study area. Table 39 shows ammonia emissions for all ports combined by sector. The table shows that most ammonia emissions are caused by agriculture, which we explained earlier in this section. The second highest emitting sector is consumers and the third highest is the chemical industry (0.35 kton), of which 0.32 kton is located in the Dutch part of the North Sea Port. The table shows that most ammonia emissions are caused by the chemical industry (0.35 kton), in the second place by agriculture (0.19 kton), and in the third place by mobility and transport (0.10 kton)

Table 39 - NH_3 emissions in port areas in the Netherlands by sector

Kton NH_3	2010	2015	2019	2020
Agriculture	0.42	0.19	0.19	0.19
Chemical industry	0.28	0.48	0.29	0.35
Construction	0.00	0.00	0.00	0.00
Consumers	0.11	0.09	0.08	0.09
Drinking water supply	0.00	-	-	-
Energy sector	0.01	0.02	0.05	0.05
Mobility and transport	0.10	0.08	0.09	0.10
Nature	0.00	-	-	-
Other industry	0.01	0.01	0.01	0.01
Refineries	0.00	-	0.01	0.01
Sewage treatment	0.00	-	-	-
Trade, services and government	0.03	0.02	0.03	0.03
Waste disposal	0.03	0.09	0.07	0.08
Total	**0.99**	**0.99**	**0.84**	**0.92**

Figure 16 shows ammonia emissions relative to added value. The Dutch part of the North Sea Port has the highest NH_3 emissions relative to added value. The Port of Moerdijk has the second highest NH_3 emissions relative to added value, after surpassing Groningen Seaports in 2019. The Port of Rotterdam has by far the lowest ammonia emissions relative to added value, and remained fairly stable between 2010 and 2020. The large decrease of Groningen Seaports is related to the relatively large increase in added value over the years, as ammonia numbers remained stable. The Port of Moerdijk is the only port that saw an increase between 2010 and 2020, which can be explained by an increase in ammonia emissions and a decrease in added value between 2010 and 2020.

Figure 17 - Ammonia (NH_3) emissions in port area relative to added value

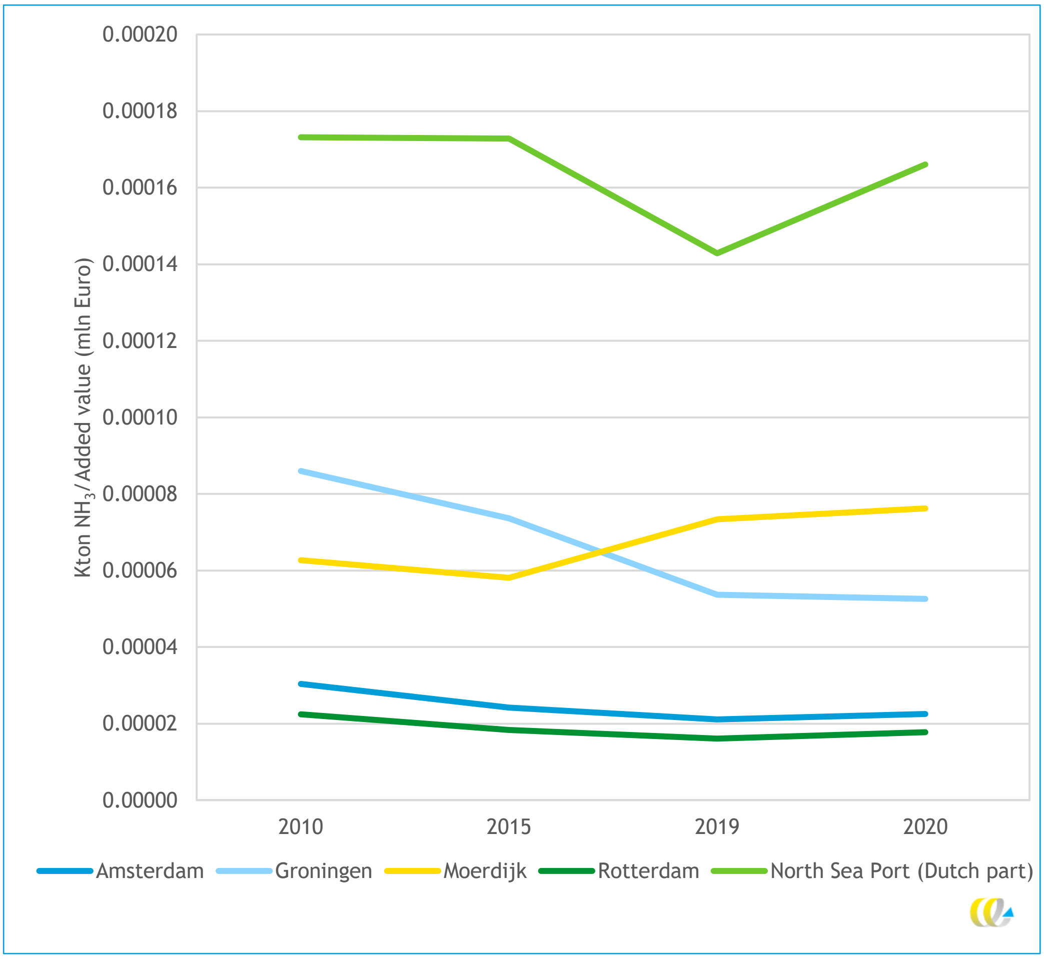


Figure 17 shows the average ammonia (NH_3) concentration in all Dutch port areas. Compared to 2011 levels, the 2021 levels for almost all ports are lower, except for the Port of Groningen, which is also the port with the highest NH_3 concentration. The Port of Moerdijk has the second highest ammonia concentration, followed by the Dutch part of the North Sea Port and the Port of Rotterdam, which have very comparable levels. The Port of Rotterdam has the lowest ammonia concentration of the Dutch port areas.

Figure 18 - Average NH_3 concentration in port areas in the Netherlands

5.4.2 Benzopyrene

Benzopyrene ($C_{20}H_{12}$) is a polycyclic aromatic hydrocarbon (PAH), a class of organic compounds composed of multiple aromatic rings. Benzopyrene emissions are formed by incomplete combustion or heating of organic material, such as wood. Sources include exhaust gasses of cars, chimney exhausts, cigarettes, bonfires, house fires and barbecues. PAH concentrations are higher in densely populated areas and during the winter. PAHs can be absorbed through food, via air or through the skin, and are a major cause of cancer. In high concentrations, they can cause damage to the skin, eyes and mucosa. Benzopyrene is the most common PAH, which is why emissions of PAHs are often measured in benzopyrene emissions.

Table 40 shows the emission for the selected Dutch ports over the years of 2010, 2015, 2019 and 2020. Emissieregistratie measured the emissions in 5x5 km squares, which are less accurate than 1x1 km squares. $C_{20}H_{12}$ emissions are the highest in the Port of Rotterdam, with the second highest emissions being at the Port of Amsterdam and Groningen Seaports (0.02 tonne). The Port of Moerdijk (0.011 tonne) and the Dutch part of the North Sea Port (0.010 tonne) have the lowest emissions. Total benzopyrene emissions decreased by almost half between 2010 and 2020. The Port of Moerdijk is the only port that experienced an increase between 2010 and 2020 (emissions more than tripled).

Table 40 - $C_{20}H_{12}$ emissions in port areas of selected Dutch ports

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Amsterdam	0.043	0.025	0.024	0.020
Groningen	0.043	0.025	0.024	0.020
Moerdijk	0.003	0.011	0.012	0.010
Rotterdam	0.083	0.049	0.043	0.038
North Sea Port -NL	0.022	0.012	0.011	0.011
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**0.155**	**0.099**	**0.094**	**0.082**

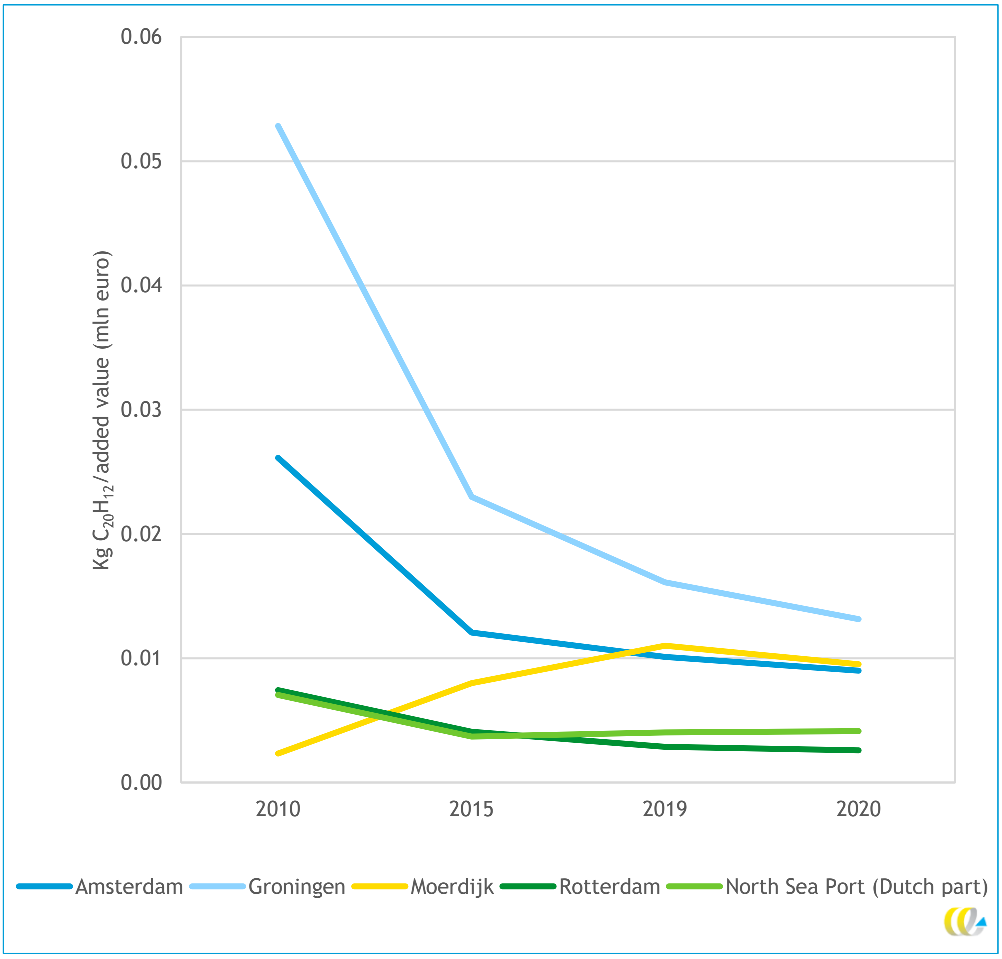
Table 41 shows emissions by sector for all Dutch ports combined. Most benzopyrene emissions originate from consumers (0.052 tonne). The second highest emissions are caused by the mobility and transport sector (0.016 tonne). The fact that consumers as a sector play such a large role in the port area, is most likely due to the inaccuracy of the Emissieregistratie 5x5 km scope. This could mean that the small inaccuracy also takes residents near the port area into account as well.

Table 41 - $C_{20}H_{12}$ emissions in port areas in the Netherlands by sector

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	0.003	0.004	0.004	0.004
Construction	0.000	0.000	0.000	0.000
Consumers	0.114	0.067	0.062	0.052
Drinking water supply	0.000	0.000	-	-
Energy sector	0.001	0.005	0.008	0.004
Mobility and transport	0.016	0.015	0.016	0.016
Nature	-	-	-	-
Other industry	0.013	0.007	0.003	0.003
Refineries	0.007	-	-	-
Sewage treatment	0.000	0.000	0.000	0.000
Trade, services and government	0.001	0.001	0.001	0.001
Waste disposal	0.000	0.000	0.000	0.000
Total	**0.155**	**0.099**	**0.094**	**0.082**

Figure 18 shows benzopyrene emissions relative to the added value for each port. The relative benzopyrene emissions are the highest in Groningen and the lowest in Rotterdam. The high emissions in Groningen are most likely related to energy production in the port area, where benzopyrene is emitted even though it does not create much added value. All ports, except for Moerdijk, experienced a decline in benzopyrene emissions between 2010 and 2020. Both Groningen Seaports and the Port of Amsterdam experienced the largest absolute and relative decrease in benzopyrene.

Figure 19 - $C_{20}H_{12}$ emissions in port areas in the Netherlands relative to added value



5.4.3 Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless, tasteless and flammable gas that is slightly lighter than air. In many countries, carbon monoxide is the most common form of fatal air poisoning. CO displaces oxygen in the blood, preventing oxygen from reaching the heart, brain and other vital organs. CO is also toxic to animals that use haemoglobin as an oxygen carrier in the blood. CO is produced in small amounts by many organisms (including humans) and acts as an endogenous neurotransmitter, but becomes hazardous in high concentrations.

Carbon monoxide can be emitted in a variety of ways. Natural sources include photochemical reactions in the troposphere, volcanoes, swamps, lightning and forest fires (which can be caused by humans). Human sources include mainly mobile sources, such as vehicles or machinery that burn fossil fuels, but also other incomplete combustion sources such as power plants, incinerators, or even the burning of wood.

Table 42 shows carbon monoxide emissions for each port area. All port areas together emitted around 47.42 kton of CO emissions in 2020. The Port of Rotterdam is the largest emitter of CO, followed by the Port of Amsterdam (which is surprising as it is the smallest port in size), Groningen Seaports, the Dutch part of the North Sea Port and the Port of

Moerdijk. Amsterdam and Rotterdam experienced a steady decrease in the years between 2010 and 2020. Groningen first saw a large decrease between 2010 and 2015, with CO emissions almost halving, and in 2019 emissions doubled again. Between 2019 and 2020, the emissions declined again by a relatively small amount. The Port of Moerdijk has seen a stable decline between 2010 and 2019, but CO emissions increased significantly between 2019 and 2020. The Dutch part of the North Sea Port experienced a slight decrease between 2010 and 2015, a slight increase between 2015 and 2019 but a large decrease between 2019 and 2020. CO emissions have been declining since 1990 due to the step-by-step tightening of European emission requirements for certain motor vehicles.

Table 42 - CO emissions in port areas of selected Dutch ports

Kton CO	2010	2015	2019	2020
Amsterdam	12.24	10.29	9.05	7.34
Groningen	9.16	4.45	10.20	8.82
Moerdijk	2.04	1.84	1.49	2.18
Rotterdam	36.95	28.37	23.33	22.74
North Sea Port -NL	9.91	9.10	10.07	6.34
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**70.30**	**54.05**	**54.14**	**47.42**

Table 43 shows CO emissions for all port areas combined, disaggregated by sector level. The table shows that the mobility and transport sector is the largest CO emitting sector in port areas as well. The second largest emitter is other industry and the third largest emitter is the chemical industry.

Table 43 - CO emissions in port areas in the Netherlands by sector

Kton CO	2010	2015	2019	2020
Agriculture	0.54	0.44	0.50	0.49
Chemical industry	8.08	8.60	10.04	7.15
Construction	0.02	0.01	0.01	0.01
Consumers	6.30	3.71	3.39	2.66
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	2.37	2.69	1.71	1.39
Mobility and transport	34.15	29.10	25.56	24.28
Nature	0.39	0.34	0.34	0.34
Other industry	11.28	2.79	9.31	7.87
Refineries	6.26	5.55	2.62	2.47
Sewage treatment	0.01	0.01	0.01	0.01
Trade, services and government	0.31	0.27	0.24	0.22
Waste disposal	0.60	0.55	0.42	0.53
Total	**70.30**	**54.05**	**54.14**	**47.42**

Figure 19 shows the carbon monoxide emissions relative to added value. Groningen Seaports has the largest relative CO emissions, followed by the Port of Amsterdam, the North Sea Port (Dutch part) and the Port of Moerdijk. The Port of Rotterdam has the lowest relative CO emissions. All ports experienced a decrease of relative CO emissions between 2010 and

2020, except for the Port of Moerdijk, which is the only port showing an increase between 2019 and 2020.

Figure 20 - CO emissions in port areas in the Netherlands relative to added value

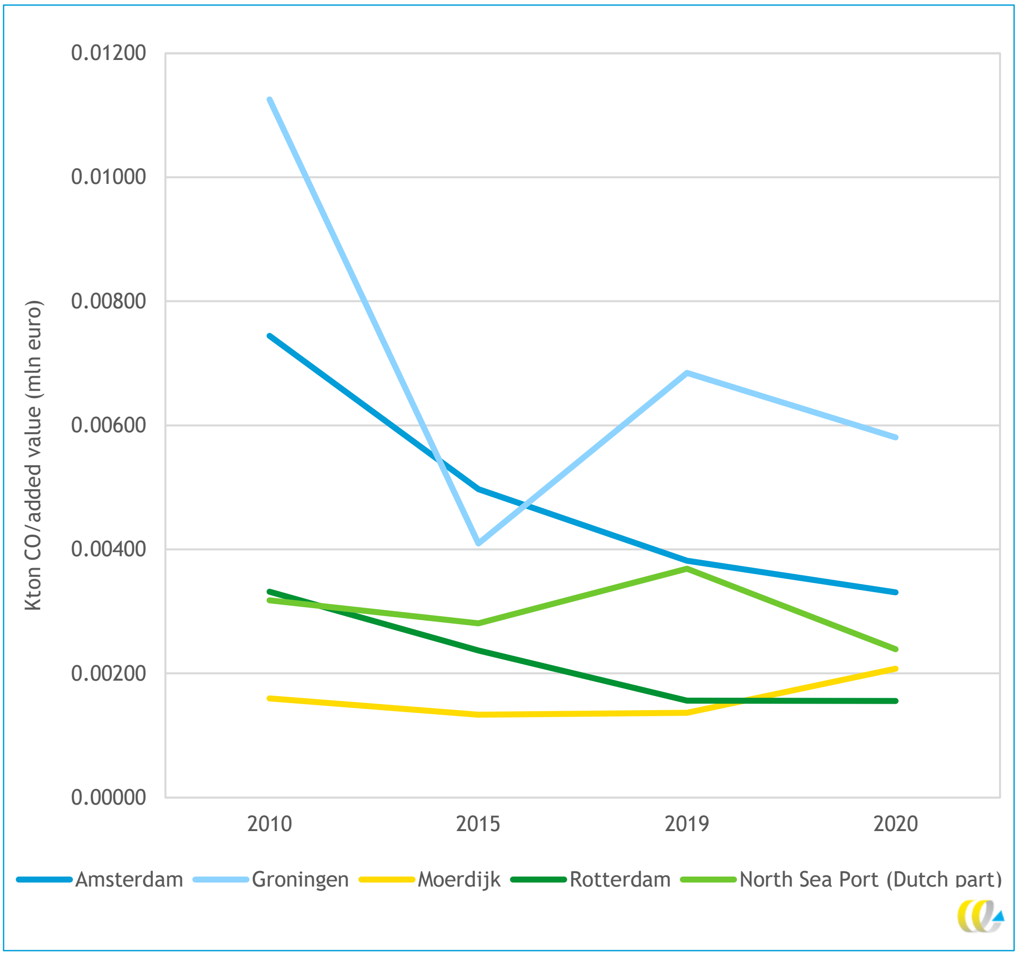
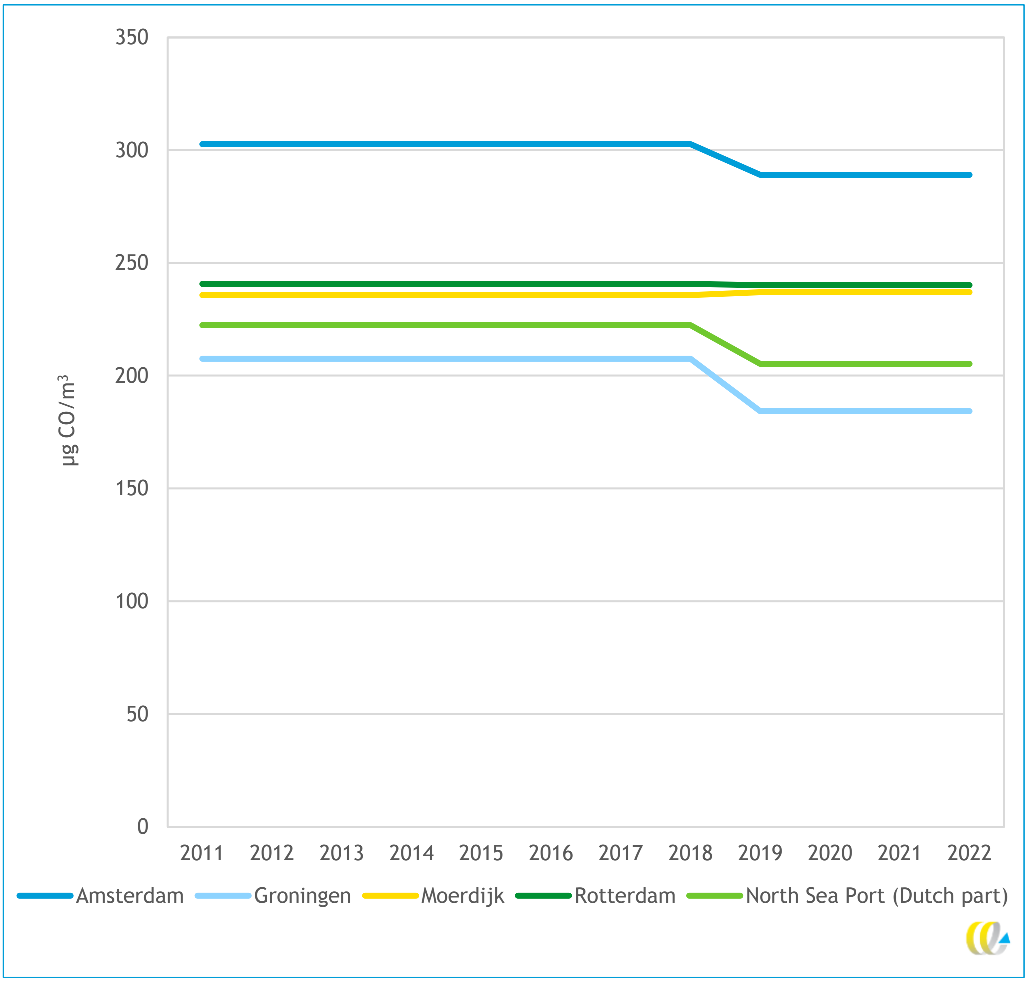


Figure 20 shows the CO concentrations for Dutch ports between 2011 and 2022. The graph is not very representative, as the concentrations are only measured once every several years. The graph does show that any increases or decreases are modest in nature, that the concentration is relatively stable and that there was a small decrease over time.

Figure 21 - Average CO concentration in port areas in the Netherlands



5.4.4 Lead

Lead (Pb) is a heavy metal that is denser than most common materials. It is highly toxic and can cause health problems. It can enter the body through food or liquids containing lead, by inhalation of dust or fumes containing lead, and through the skin.
Historically, lead has been used in a variety of ways, such as in lead water pipes, in paint and ceramic glazes, as typeface and for coffins. Lead was used in petrol as an effective anti-knocking agent, but all countries banned this practise between 1986 and 2021 due to large amounts of lead entering the human body.

Today, the largest sources of lead emissions are the ore and metals industry, piston-engine aircrafts using leaded gasoline and waste incinerators. Lead can easily bind itself to particulate matter and form a health risk to people living in the vicinity of these industries. Lead-contaminated particulate matter can be deposited on crops and grasses used for agriculture and enter the body through food. Lead is mostly stored in the bones, but a fraction will end up in the blood. Cardiovascular diseases and kidney failure can be the result. Exposure to high quantities can result in lead poisoning. Exposure to lead is even more dangerous to children because of their higher metabolism and ability to store higher levels of lead.

Table 44 shows lead emissions for all port areas studied. In 2020, the Port of Moerdijk had by far the highest lead emissions, followed by the Port of Rotterdam, the Port of Amsterdam, Groningen Seaports and the Dutch part of the North Sea Port. Some ports show a large variation between 2010 and 2020. The Port of Moerdijk experienced a large increase between 2010 and 2020. In contrast, the Port of Rotterdam and the Dutch part of the North Sea Port experienced a very large decrease between 2010 and 2020. In the case of the Dutch part of the North Sea Port, the large emissions in 2010 were caused by one company, which ceased production in 2012 due to bankruptcy. In 2017, a glass producer was responsible for a much larger than usual increase of lead at the Port of Moerdijk (CE Delft, 2020). The numbers in 2018 and 2019 continue to be quite high.

Table 44 - Lead emissions in port areas of selected Dutch ports

Ton Pb	2010	2015	2019	2020
Amsterdam	0.09	0.08	0.08	0.09
Groningen	0.08	0.01	0.07	0.08
Moerdijk	0.07	0.07	0.38	0.99
Rotterdam	0.71	0.60	0.10	0.10
North Sea Port -NL	2.99	0.05	0.01	0.01
North Sea Port -BE	n/a	n/a	n/a	n/a
North Sea Port	n/a	n/a	n/a	n/a
Total	**3.94**	**0.81**	**0.64**	**1.28**

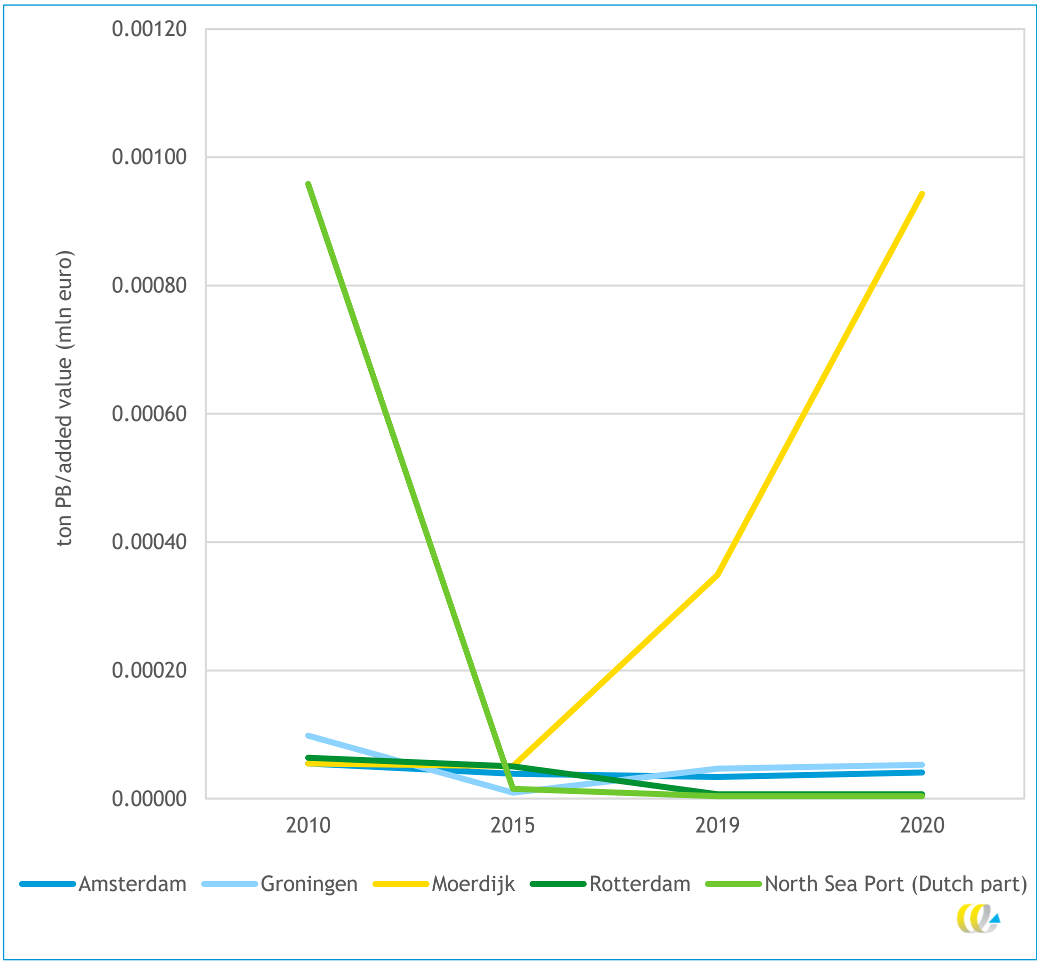
Table 45 shows the total emissions of all ports by port sector. By far the largest emitter in 2020 was other industry, followed by waste disposal and mobility and transport, which is in line with the previously mentioned main emitters of lead. A large decrease is visible between 2010 and 2020, almost cutting lead emissions by two-thirds. However, there was a large decrease between 2019 and 2020, which doubled the emissions.

Table 45 - Lead emissions in port areas in the Netherlands by sector

Ton Pb	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	2.99	0.04	0.02	0.02
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.02	0.02	0.02
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.01	0.00	0.00	0.00
Mobility and transport	0.09	0.08	0.09	0.09
Nature	-	-	-	-
Other industry	0.65	0.58	0.43	1.04
Refineries	0.01	0.01	0.01	0.01
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.17	0.07	0.08	0.10
Total	**3.94**	**0.81**	**0.64**	**1.28**

Figure 21 shows the relative lead emissions compared to the added value. Most striking are the high values for the Dutch part of the North Sea Port in 2010, and the high values for the Port of Moerdijk in 2019 and 2020. In the previous section, we already explained the high values for these ports. The intensity of lead emissions decreased in all ports between 2010 and 2020, except for Moerdijk.

Figure 22 - Lead emissions in port areas in the Netherlands relative to added value



5.5 Conclusions

The air quality in most Dutch and international ports is monitored using sensors, often in combination with modelling exercises. The monitoring is usually performed by environmental agencies, but port authorities are often involved themselves.
For example, by sponsoring new sensors or by carrying out a detailed project. This chapter has shown that emissions of most substances are decreasing in port areas:

- Concentrations of nitrogen oxides are significantly lower compared to a decade ago. This applies to Dutch ports, but also to international ports. The emissions in Dutch ports in 2020 are quite similar to the emissions in 2015 and the large reduction has not continued. This is mainly due to increases in The average concentration of nitrogen oxides has, however, continued to decrease. The recent improvement in air quality is therefore due to emission reductions outside the port.
- Emissions of particulate matter have continued to decrease in most ports. Only in Antwerp have results been stable in recent years. Transport is a major source of particulate matter and stricter emission standards, among other things, have led to

reductions over time. The concentrations of particulate matter are decreasing in general, although there are annual fluctuations.

- Emissions of other substances are often influenced by individual occurrences. In particular, large companies can have high incidental emissions. In the long-term, however, emissions are decreasing.
- Concentrations of main air quality pollutants are also measured in most international ports. Emission modelling is less common, which is to be expected as the efforts involved in modelling individual sources are greater. Reductions are also visible at international ports.
- The COVID-19 pandemic and the lockdowns lead to reductions in emissions and concentrations. Especially passenger traffic was reduced which mainly occurs outside port areas. In some ports emissions from shipping increased due the pandemic as shore-power facilities where not available during lockdowns.

6 Mitigation measures

There are multiple ways for ports to reduce their climate and air pollutant emissions. We identify two types of solutions: industrial and transport related solutions. Examples of industrial solutions are the use of residual heat and/or steam and carbon capture. Localised measures can also help to improve air quality, such as environmental zones and shore power for shipping. The information is based on publicly available data, which means that not all solutions are included. Annex A lists all the data sources used. In Section 6.1 we discuss the industrial solutions taken by the various ports. The transport-related solutions are discussed in Section 6.2.

6.1 Industrial solutions

In many ports, solutions are being implemented that result in CO_2 reductions. These mitigation measures reduce the production of CO_2 emissions elsewhere. By using biomass from renewable origin, less coal and gas is used for the production of energy. In industrial facilities and waste incineration, heat is often a by-product. This residual heat can be used by other companies or used to feed an urban heating network. Carbon capture usage and storage solutions are included as well. At the North Sea Port, a pipeline transports hydrogen from a company where it is by-product to another company for input. Table 46 shows a comparison of the total emission reduction in Mton CO_2. In particular, large scale biomass incineration leads to large CO_2 reductions. Biomass solutions are discussed in more detail in Section 6.1.1. In Section 6.1.2, we discuss the various heat and steam systems in more detail. Finally, in Section 6.1.3, carbon capture usage and storage solutions are discussed. Detailed sources are provided in Annex A. We have not looked at projects which are not operational yet.

Table 46 - Annual CO_2 reduction form mitigation measures in 2021

Mton CO_2	Biomass	Residual heat and steam	Carbon capture and usage	Carbon capture and storage	Hydrogen pipeline	Total
Amsterdam	0.005**	0.096	-	-	-	1
Groningen	1.4**	0.110	-	-	-	1.51
Moerdijk	0.123	0.12**	-	-	-	0.135
North Sea port	0.088	0.015	0.475	-	0.01	0.588
Rotterdam	1.92*	0.02	0.6	-		2.52
Antwerp	0.1*	0.1*	-	-	-	0.1
Hamburg	-	0.032	-	-	-	0.032

* Includes residual heat.

** Figures are based on energy use and greenhouse gas intensity of gas power stations.

6.1.1 Biomass

Biomass is organic material that can be used to generate energy or used as a raw material for industrial processes. The most commonly used biomass materials are wood, plants, crops and waste. Biomass can be incinerated to create heat or power, it can be processed into biofuels or biogas or it can generate electricity by direct combustion. Depending on the type of use, biomass can be a carbon-neutral solution. Plants and trees absorb CO_2 during their life cycle to grow and convert the CO_2 into biomass. When biomass is burned CO_2 is emitted, but it is considered climate-neutral due to the CO_2 emissions previously absorbed. An example of this is the generation of biomass using production forests. If the annual harvest in the landscape, in order to create wood products, does not surpass the annual growth level of the production forest, then there will be no reduction in forest carbon.

Text box 1 - Sustainability of Biomass

When used correctly, biomass is a sustainable source of energy. However, renewable energy production using biomass, especially wood pellets, is highly debated globally and in the Netherlands in terms of its sustainability. The debate mainly concerns the use of wood pellets as a replacement for coal in power plants. These wood pellets are often imported. The increased demand for biomass has made it unclear whether sufficient amounts of biomass could be produced in a sustainable manner in the future, i.e. without any negative impact on the climate, biodiversity and food supply.

Sustainability depends on the origin of the biomass and how it is harvested, transported and treated. Land use and soil exhaustion are two important factors. A key requirement is that land used for biomass production should not replace existing trees or fields used for food production. Another key requirement is that forests are regenerated and that carbon stock levels and carbon uptake capacity in the forest are at least maintained. In order to properly assess the sustainability of biomass, the complete life cycle of the bioenergy system should be compared with the situation without bioenergy. Certification of biomass ensures that biomass is produced, used and managed in a sustainable way. For example, the Better Biomass certificate has been awarded to a biomass plant in Groningen. Sustainability can also be guaranteed by a study using life-cycle analysis, such as that undertaken by a manure incinerator in Moerdijk (CE Delft, 2017a).

Biomass is currently used in the ports of Moerdijk, Rotterdam, Groningen, North Sea Port and Amsterdam.
- The Port of Amsterdam houses a bioenergy plant that produces heat and electricity. The precise CO_2 reduction is unknown, but it produced about 1,700 TJ of heat in 2021.
- In Moerdijk, there is a company that converts poultry manure into electricity. According to a report by CE Delft, the reduction of CO_2-eq. per tonne of processed manure is almost 300 kg (CE Delft, 2017b). The average annual production of 420,000 tonnes of manure leads to a reduction of about 123 kton CO_2 per year.
- A bio-energy plant announced in 2021 that it would shortly relocate to the site of Groningen Seaports. It will create BioLNG and high-purity CO_2 from of industrial waste, and process high volumes of industrial biomass in a more environmentally sustainable way. There is also a power station located at Groningen Seaports that uses supercritical pulverised coal and biomass with a capacity of 1,600 MW and a specific biomass power station. There is also a company producing fuels from waste situated in Groningen Seaports.
- In the Port of Rotterdam, there are power plants that run partially on biomass (wood pellets). A waste incinerator also partly uses waste of biogenic origin classified as biomass.
- In the North Sea Port, there are multiple businesses that use biomass to generate energy in order to supply their own heating warmth, electricity or use bio-gas installations that are powered by agricultural waste (North Sea Port, 2023). A company in the North Sea Port creates biomass out of the residue that remains after creating sustainable fuel.

6.1.2 Heat and steam

The use of residual heat is one of the most commonly used mitigation measures. Heat is a by-product produced during certain production processes. This residual heat can be used by other processes as input, for example to feed a heating network.

- In Groningen, Amsterdam and Rotterdam, residual heat is used to feed a heating network. As a result, less fossil fuels are used for the district heating, which means less CO_2 emissions are being emitted.
- In Groningen there is a steam network powered by residual heat from Waste incineration (EEW). This steam network powers multiple companies which otherwise would depend on gas to generate steam.
- In the Port of Moerdijk, a waste incineration plant produces steam that can be converted to electricity by a steam turbine. The steam turbine has an electrical capacity of more than 120 MW. Because the steam turbine can be used to generate electricity, the term residual heat might be misleading.
- At the North Sea Port, a fertilizer plant and other companies produce residual heat that is being used by greenhouses and a car manufacturer. The car manufacturer reduced its CO_2 emissions by 15,000 tonnes per year because of the residual heat. Pipelines run underneath a bicycle path that remains ice free in the winter because of the heat.
- In Antwerp, residual heat from an industrial complex is used to feed a steam network to other companies in the port.
- In Hamburg, there is an industrial heat system that will probably be expanded in the future.

Text box 2 - Waste incineration

Incineration of residual waste can produce energy in the form of fuel, electricity or heat. This heat can be used to feed district heating or as energy for industry. Part of the residual waste processed in a waste incinerator is biomass, such as paper and food. The carbon released when burning this biomass has been absorbed at an earlier stage, making it a renewable and carbon-neutral form of production. The energy from this biogenic part of waste is considered renewable energy under Dutch law. About 50% of all incinerated waste in the Netherlands is of biogenic origin. Incinerating waste to produce electricity is therefore partly a renewable energy source. The capacity of waste incinerators has not been included in Section 6.1 as only part of the capacity is used to produce renewable energy. Incinerated residual waste can also be used to produce heat or steam, as is the case at the Port of Moerdijk. In the case of Moerdijk, the term residual heat is somewhat misleading as the heat produced can be used to generate electricity with a back-pressure turbine.

6.1.3 Carbon capture storage and usage

The Netherlands has produced more renewable energy in recent years and will continue to do so in the coming years. For certain purposes, fossil fuels will remain relevant in coming decades. For many industrial facilities, the use of fossil fuels is embedded in the production processes and adjustments are not easy to make. A switch to green hydrogen or electricity is the preferred option for many facilities. However, the availability of green hydrogen is currently limited and price levels are high. A switch to sustainable energy in industrial facilities will take time. Carbon capture storage (CCS) and usage (CCU) are quicker solutions that can allow for a longer use fossil fuels without leading to increased global warming.

Carbon capture and storage

Dutch ports are starting to look at larger scale carbon storage solutions:
- The Porthos project[10] in Rotterdam, which could store up to 37 Mton CO_2 in empty gas fields in the North Sea. Similar solutions are being investigated in Amsterdam, Groningen and Moerdijk[11].

10 https://www.porthosco2.nl/

11 https://projecten.topsectorenergie.nl/projecten/decarbonizing-the-industry-in-moerdijk-by-managing-emissions-regionally-36253 https://www.aebamsterdam.nl/nieuws/co2-opslag-door-aeb-stap-dichterbij/

- The North Sea Port and the Port of Antwerp are investigating at several solutions, including capturing CO_2 and transporting CO_2 by vessel for long-term storage[12].
- All of these solutions are currently being investigated and are in various stages of implementation. Projects have progressed in recent years, but no real world examples are available as yet.

Carbon capture and usage

Another solution for reducing climate emissions is the reuse of carbon emissions. Carbon emissions are used in horticulture or can be used for fuels. The emissions from fossil fuel do thus not end up in the air directly, but are captured in plants or fuels. Ultimately the carbon emissions do still end up in the air but the carbon does not have to produced separately. Production of carbon is thus mitigated. Several smaller-scale projects are currently underway in Dutch ports:

- The Port of Rotterdam has a CO_2 pipeline connected to a greenhouse horticulture area. CO_2 from industrial facilities is used to speed up the maturing process of plants. An expansion of the network increased the supply of carbon emissions from 0.25 Mton in 2018 to 0.6 Mton in 2021. A similar carbon network for horticulture is in place in the North Sea Port where residual heat (76 MW capacity) and about 55 kton of CO_2 are transported.
- Another initiative in the North Sea Port is the use of residual CO_2 for soft drinks, where about 0.1 Mton is reused annually. In 2022, a new installation opened which produces ethanol from carbon-rich residual gases. Annually, this could reduce up to 0.125 Mton in CO_2 emissions.
- At Groningen Seaports, a large demonstration scale plant opened in 2021, producing renewable chemicals from CO_2 (Photanol, 2022). In the port there are also plans for a methanol production facility which uses captured carbon (EEW, 2022a).

6.2 Transport solutions

Transport emissions are another source of emissions in port areas besides industrial facilities. Transport emissions occur due to shipping, but also due to road and rail transport. Transport air pollutant emissions are often emitted at low altitudes, making the damage relatively higher compared to emissions from chimneys. In this chapter, we discuss the various measures taken by ports to reduce emissions from transport.

6.2.1 Environmental zones

Low-emission zones are a measure taken in ports to reduce emissions of mainly air pollutants. These measures target various modes of transport, including road transport, maritime shipping and even transhipment infrastructure. In this section, we discuss environmental zones set up in various ports.

- There are a few environmental zones for maritime shipping around the world. These include the North Sea and the American west coast. These emission zones limit the emissions of SO_x and, in certain cases, also NO_x. In America, NO_x has been regulated for some time, while in the North Sea and the Baltic sea this was introduced in 2021. SO_x emissions are controlled by the sulphur content of fuels, while the NO_x emissions are

[12] https://stad.gent/nl/ondernemen/economische-speerpunten/cleantech-cluster-regio-gent/projecten-partnerschap/carbon-capture-utilization-hub https://www.northseaport.com/yara-in-north-sea-port-zorgt-voor-mijlpaal-voor-vervoer-en-opslag-van-co2

regulated through engine standards. Both measures limit emissions from maritime vessels while at sea and at berth. All ports except Barcelona are in low emission zones.
- The ports of Los Angeles and Long Beach have a unique voluntary vessel speed reduction programme. This incentive aims to reduce particulate matter, nitrous oxides and greenhouse gases. It intends to reduce sailing speeds of vessels entering the port from 20 or 40 nautical miles before port entry. Vessels reducing sailing speeds receive an annual financial incentive. In 2021, compliance with both zones was above 90%.
- Several ports have low emission zones for trucks. This includes the ports of Rotterdam, Long Beach, Los Angeles and Vancouver.
- The ports of Los Angeles and Long Beach have a programme to reduce emissions from port infrastructure. This includes trucks that are used within the port as well as using latest technologies for cargo-handling equipment. Also, the use of idling for trains is minimised to reduce emissions.

6.2.2 On-shore power

Vessels at berth still have energy consumption and corresponding emissions. For maritime vessels in particular, these emissions can be significant. This is why on-shore power is, alongside alternative fuels, one of the main targets for sustainable shipping in the European 'Fit for 55' package. The regulation mandates the use of shore power from 2030 for a selection of vessel types in European ports. This regulation has accelerated the development of shore power for maritime vessels. Shore power for inland vessels has become standard at many larger ports. In this section, we start by discussing maritime vessels, followed by inland vessels.

Maritime vessels

Due to the size of maritime vessels, power demands can be very high. As a result, the solution is costly and current uptake is limited in European ports. In Rotterdam, there are currently two connection points. Since 2012, ferry services to the United Kingdom connect to on-shore power and a new OPS connection for a marine contractor was opened in 2022. Hamburg is an European port that also has a maritime OPS connection for cruise vessels. The Port of Le Havre has opened a maritime OPS connection as well. However, many ports are investigating new facilities. These include Moerdijk[13], Rotterdam[14] and Hamburg[15]. The ports in North America already offer significantly more connection points for shore power. Table 47 shows the number of connection points by port. Especially in Long Beach and Los Angeles, there are many connection points.

Table 47 - Number of OPS connection points for maritime shipping

Number of OPS connection points	2022
Rotterdam	3
Hamburg	1
Le Havre	1
Long Beach	79
Los Angeles	81
Vancouver	8

13 www.scheepvaartkrant.nl/nieuws/ook-walstroom-voor-zeevaart-op-moerdijkse-havenkades
14 https://innovationorigins.com/nl/na-de-binnenvaart-nu-ook-zeeschepen-in-aan-de-stekker-in-rotterdam/
15 www.hafen-hamburg.de/en/press/news/landstrom-fuer-containerschiffe-in-hamburg/

The connection points in North America are a consequence of specific policies. California, which includes the ports of Los Angeles and Long Beach, has specific regulations on the use of shore power. Vessel operators, being the shipping lines, are obliged to meet mandatory levels of shore power usage. From 1 January 2014, fleets calling at California ports must turn off their auxiliary engines and plug in to the electrical grid while at berth. Fleets must plug in at the following levels and reduce onboard power or emissions by the levels listed in Table 48.

Table 48 - Shore power regulation levels

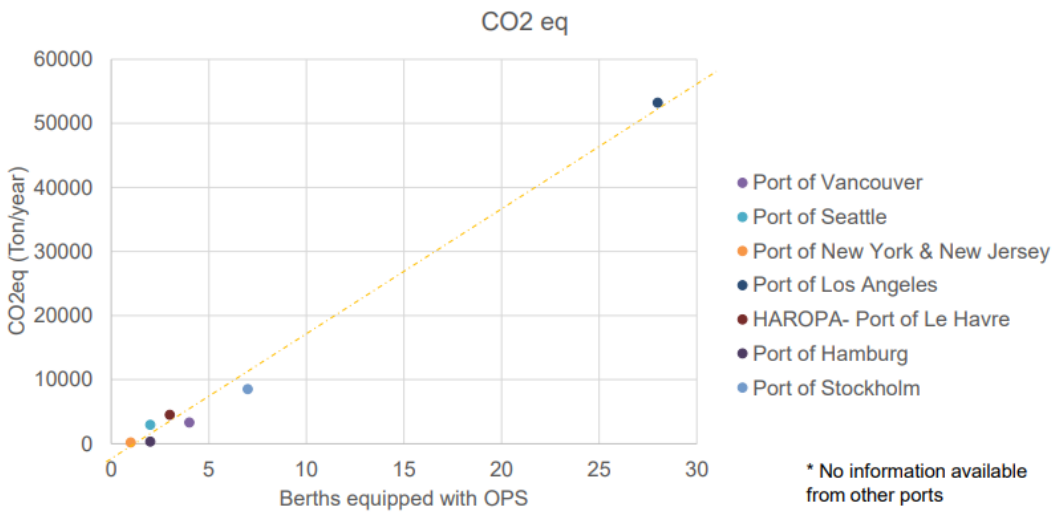
Years	% of fleet's visits to each California port
2014-2016	50%
2017-2019	70%
2020+	80%

Additionally, if a ship is currently equipped for shore power and a shore power-ready berth is available, the ship must plug in to shore power. The regulation applies to container ships, reefer vessels, and cruise ships. New requirements will come into effect in early 2023 that will also apply to tankers and roll on-roll-roll-off vessels. The Port of Vancouver has a voluntary system whereby vessels using shore power receive a 75% discount on port charges.

Use of shore power

The use of shore power differs considerably between ports. In Los Angeles and Long Beach, the regulation targets were met and over 80% of visiting container and cruise vessels used shore power. However, some of the connection points are only used sparsely: this specifically applies to cruise vessels during the COVID-19 pandemic. In Vancouver, GHG emissions decreased from 4,366 tonne in 2019 to 291 tonne in 2020. In 2022, the reduction reached a record high of 6,866 tonne.

Figure 23 - CO_2 reduction from OPS for selected ports



Source: (Cenit & Port De Barcelona, 2020).

Inland vessels

The use of on-shore power at berth is common practice for inland waterway vessels. This is illustrated in Table 49 by the large number of connection points that are installed. In Rotterdam and part of the Port of Amsterdam, the use of on-shore power is mandatory.

Table 49 - Number of OPS connection points for inland waterway transport

Number of OPS connection points	2018	2019	2020	2021
Amsterdam	n/a	n/a	n/a	53
Groningen	229	229	229	229
Moerdijk	10	10	10	10
Rotterdam	n/a	n/a	480	n/a
North sea port	68	80	n/a	82
Antwerp	n/a	n/a	n/a	25
Bremen ports	21	21	20	20
Le Havre	n/a	n/a	n/a	14

Table 50 shows the amount of on-shore power supplied to inland waterway transport. The results are not reported by all ports supplying shore power to inland vessels. In absolute terms, the energy use of inland vessels is small. In Rotterdam, about 5,000 MWh was supplied to ferries using two connection points in 2019. In the same year, 1,206 MWh was supplied via the 480 connection points (Port of Rotterdam, 2022b).

Table 50 - Onshore power supplied (MWh) inland waterway transport

MWh	2018	2019	2020	2021
Groningen	1,114	1,113	1,396	1.495
Rotterdam	1,217	1,206	855	1,147

Port fees

One means to support sustainable shipping is to offer discounts on port charges to sustainable vessels. For maritime vessels, discounts are often granted via the Environmental Shipping Index (ESI). This programme measures the performance of vessels and provides a sustainability score. As shown in Table 51, ports offer various levels of discounts depending on the environmental performance of vessels. Discount levels and thresholds differ by port. Groningen Seaports offers a relatively low discount for a larger number of vessels compared to the other ports. North Sea Port offers higher discounts, but only for vessels with a score above 50.

Table 51 - Minimum ESI score in order to receive a discount in 2021

Minimum ESI score to receive discount	Discount	Minimum score	Dependent on
Amsterdam		25	ESI score, type of fuel and size of vessel.
Groningen	Max. 5%	20	
Moerdijk	10%	31	Only applies to first 20 port calls per seagoing vessel per quarter.
North sea port	5%-15%	30	5% between 30 and 40; 10% between 40 and 50; 15% when above 50.
Rotterdam	10-20%	31	Only applies to first 20 calls per seagoing vessel per quarter. The discount is doubled if the ESI-NO_x is higher than 31 as well.
Antwerp	4% - 15%	31	4% between 30 and 50; 10% between 50 and 70; 15% when over 70.
Barcelona	No		
Bremen	15%	45	A total of 25 ships with the best ESI score will receive a discount of 15 per cent per port call per quarter, up to a maximum of € 4,500.
Hamburg	0%-10%	20	Vessels with an ESI air score over 20 points will receive a discount of up to 7%; vessels with an ESI noise score over 40 points will receive a discount up to 3%.
Le Havre	0-50%	44	For sail and wind powered vessels, an ESI incentive of up to 50% of the port charges for the ship according to conditions laid down by the Port of Le Havre.
London	10%	30	by 10% if they score 30. The discount is doubled for scores above 50.
Long Beach	Not applicable	25	ESI score from 25 to 47 is eligible for $ 600; ESI score from 48 to 53 is eligible for $ 3,000; ESI score of 54 or above is eligible for $ 6,000; a $ 3,000 Tier III 'plus-up' incentive may be combined with the ESI score-based incentive, meaning a vessel could be eligible for up to $ 9,000 on every port call.
Los Angeles	Not applicable	40	ESI score of 50 or above: $ 2,500 per port call ESI score of 40-49: $ 750 per port call. In addition, an OGV with an IMO Tier III Propulsion Engine will receive $ 5,000 per

Minimum ESI score to receive discount	Discount	Minimum score	Dependent on
			port call. An OGV participating in an Engine Emission Reduction Technology Improvement Demonstration will receive $ 750 per call-up.
Vancouver	23%	25	ESI above 50 are eligible for a 47% discount; between 36 and < 50 are eligible for a 35% discount; between 25 and < 36 are eligible for a 23% discount; vessels with an ESI noise score are eligible for a 23% discount.

Discounts for environmentally friendly vessels are also offered in all ports. Table 52 shows the discounts offered for inland waterway vessels. The lowest discount is offered in Groningen. In Amsterdam, vessels with a platina certificate, which can sail without emissions, are awarded a higher discount which encourages higher investments. However, as discussed in (CE Delft, 2022), the discount levels alone are not sufficient to finance a switch to a different type of propulsion. The Port of London uses a specific system to promote green inland vessels called Thames Green Scheme.

Table 52 - Green Award discounts offered in 2021 for inland waterway vessels

Minimum ESI score to receive discount	Discount on port dues	Minimum score	Dependent on
Amsterdam	5-20%	Green award certificate	Bronze/silver/gold/platina certificate
Groningen	5%	Green award certificate	No difference between certificates
Moerdijk	15%	Green award certificate	No difference between certificates
North sea port	10%	Green award certificate	No difference between certificates
Rotterdam	15%	Green award certificate	No difference between certificates
Antwerp	7-15%	CCRII emission limit	Higher discounts available for engines with recent emission standards
Bremen	10%	Stage II emission limit	No difference between emission standards
Hamburg	30%	NRMM emission Stage V	Surcharges up to 15% available for engines with old emission standards
London	Depends on incentive provider	14 of 100 according to Thames Green Scheme	Number of employees, corporate scores and average vessel score

6.3 Conclusions

In ports, there are various measures to mitigate emissions of greenhouse gases and air pollutants. These can be divided in measures related to industrial facilities and to transport. We have shown that in ports with industrial facilities, biomass, residual heat and carbon capture and usage already play a role. Compared to the absolute emissions in ports, the benefits of mitigation measures are limited but definitely significant. Many ports are starting projects for carbon capture and storage solutions in empty gas fields. These projects are becoming more concrete and probably will become operational in the next five years. The availability of data on this topic is limited for foreign ports and no conclusions can be drawn regarding frontrunners or laggers. Mitigation measures aimed at transport solutions are more prolific in Los Angeles and Long Beach:

- These port have a long history of NO_X environmental zones for shipping, which have also recently been implemented in North Europe.

- The ports offer good facilities for shore power for container vessels. This is combined with policies mandating the use of shore power or significant reductions in emissions. The uptake of shore power is a lot higher compared to European ports. This could be helpful to European ports for the introduction of new regulations regarding shore power.
- The ports of Los Angeles and Long Beach have an incentive program to promote slow sailing, leading to reductions in energy use and emissions. The programme currently has compliance rates of over 90%. The programme is quite unique as it is not common for ports to offer speed incentives. Vessels that reduce speeds are offered a discount on port fees.

Many ports offer discounts for environmentally friendly vessels. Currently, this takes place via the ESI score system. Compared to the previous edition of this benchmark, use of this ESI score system has increased significantly. Of the ports studied, only Barcelona does not offer discounts according to the ESI score system. Discount levels differ quite significantly between ports, indicating that there could be potential scope to offer higher discounts in certain ports.

7 Renewable energy

This chapter discusses the production of renewable energy in ports. Firstly, we discuss the results of renewable electricity production in port areas. Secondly, we look at the production of biofuels.

7.1 Production capacity electricity

Current capacity

The production of solar and wind energy is weather dependent and as a result the annual output is weather dependent. For this reason, production capacity is a better instrument to measure renewable energy efforts. Table 53 shows the renewable energy capacity in various port areas. The Port of Groningen, situated in less populated area, covers a relatively large area and positions itself as an energy port. It has a significant amount of renewable energy capacity, although this is still limited compared to capacity including fossil power stations (8,000 MW (Groningen Seaports, 2023)). The coal fired power stations, located in Groningen and Rotterdam (not included in table), can also be partially fuelled by biomass. The ports of Groningen, Rotterdam and North Sea Port are locations where offshore wind is connected to the main high voltage electricity network.

International ports have, in general, less renewable energy production capacity on their sites. For certain ports, this is a consequence of a lack of space or close proximity to urban areas. The Port of Barcelona cannot build wind turbines because of its proximity to an airport. The Port of Antwerp, one of the largest ports by size, has installed significant renewable energy capacity. The ports of Bremen, Le Havre and Vancouver do not have renewable energy installed or do not report on it.

Table 53 - Renewable energy production capacity (MW) in 2022 or latest available year

MW capacity	(Certified) biomass power station	Solar	Onshore Wind	Offshore wind	Other
Amsterdam	40	7	77	-	-
Groningen	235*	54	414	600	-
Moerdijk	32	35	25	-	-
North Sea port	20	110	300	1,500	1.6
Rotterdam	20	18	195	1,400	-
Antwerp	-	70	330	-	-
Barcelona	-	7	-	-	-
Bremen	-	-	-	-	-
Hamburg	-	42	-	-	1.3
Le Havre	-	-	-	-	-
London		2.3	-	-	-
Long Beach	-	0.9	-	-	-
Los Angeles	-	13	-	-	-
Vancouver	-	-	-	-	-

* of which 135 MW Thermic.

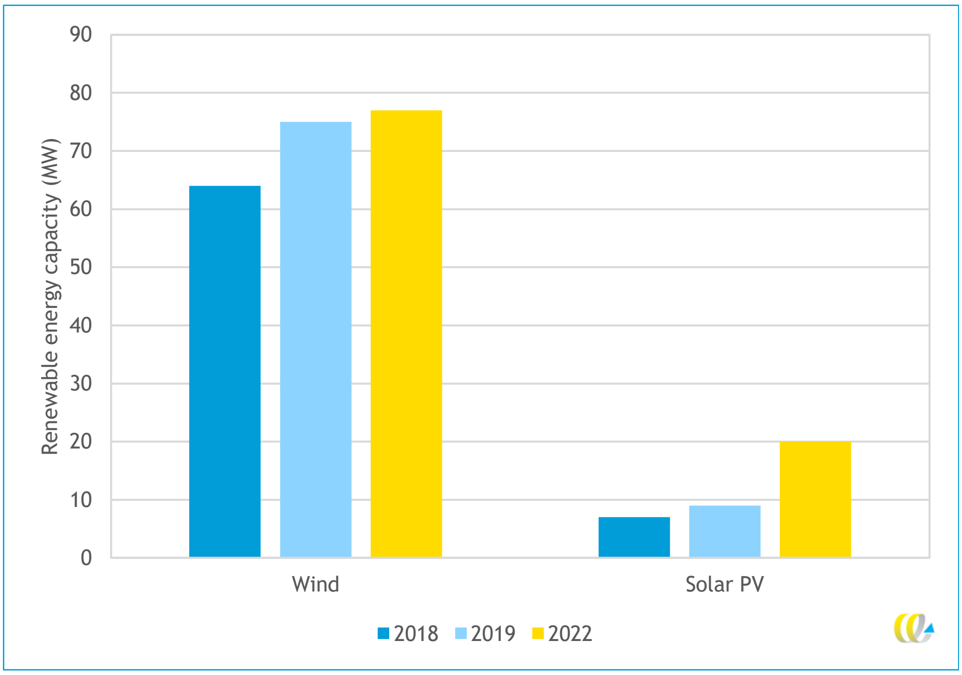
Historical development

A direct comparison of renewable energy capacity is not very relevant as ports differ in size and capabilities. However, a comparison over time is relevant as it shows to what extent ports are able to develop renewable energy within their own limits. The information in this chapter is partly based on the results presented in the previous edition of the benchmark. The results include those ports for which long-term results are available.

Amsterdam

The development of renewable energy production capacity at the Port of Amsterdam is shown in Figure 23. The capacity is available for the years 2018 to 2022. In these years, there was a modus growth of wind power while solar power has growing relatively fast. In absolute terms, wind energy remains a more important source of renewable energy.

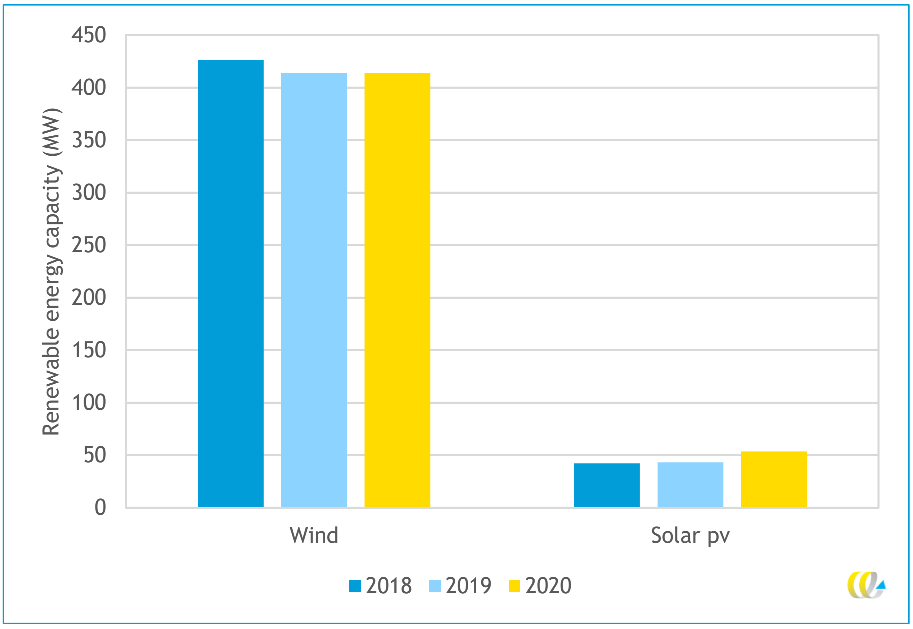
Figure 24 - Renewable energy capacity at Port of Amsterdam



Groningen

Figure 24 shows the renewable energy capacity of Groningen Seaports. The results are available for the years 2018, 2019 and 2020. In these years, there was a slight decrease in wind energy, while the capacity for solar power increased steadily. It is not clear why the wind energy capacity has decreased slightly.

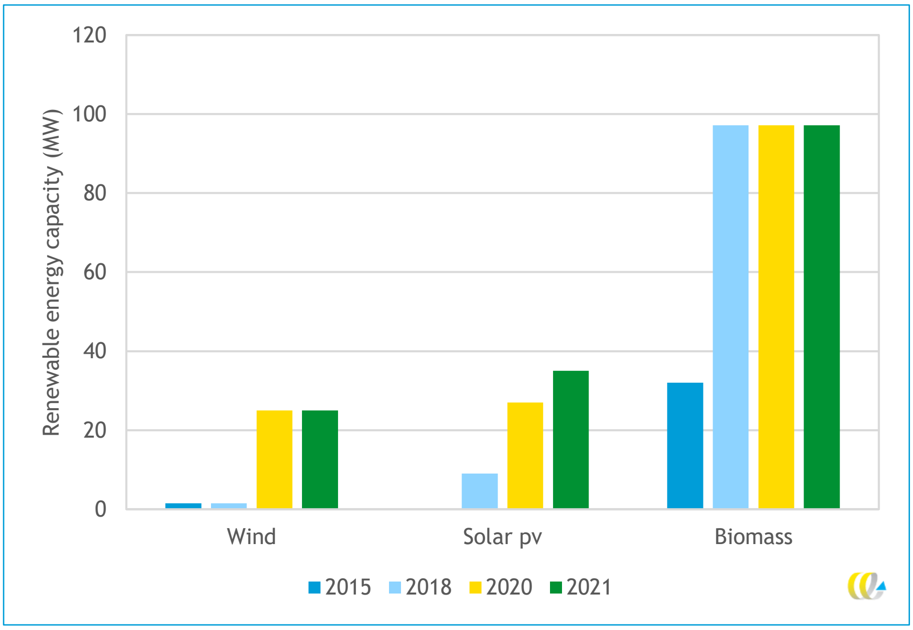
Figure 25 - Renewable energy capacity at Groningen Seaports



Moerdijk

The Port of Moerdijk has capacity information about power from wind, solar and biomass. The results are available in Figure 25 for a selection of years from 2015 onwards. The opening of a new wind park resulted in a large growth between 2018 and 2019 of wind power capacity. Similarly, a new waste incinerating facility opened between 2015 and 2018. This allowed more energy to be produced from waste of biogenic origin. The capacity of solar energy grew steadily from 2018 to 2020.

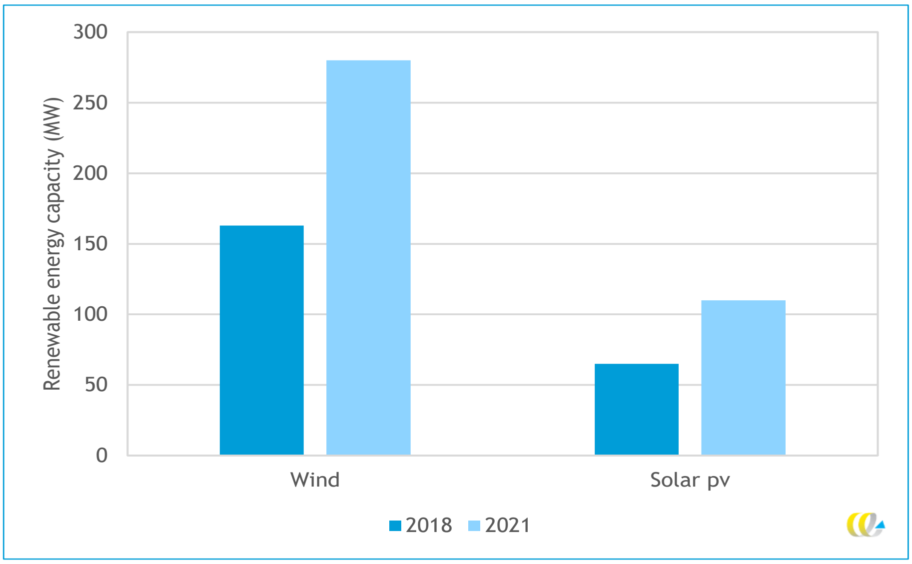
Figure 26 - Renewable energy capacity at Port of Moerdijk



North Sea

The ports of Zeeland and Ghent merged in 2018 to form North Sea Port. The results in 2018 taken from the previous study only included the Dutch part of North Sea Port. This is part of the explanation of the growth of renewable energy capacity in Figure 26.

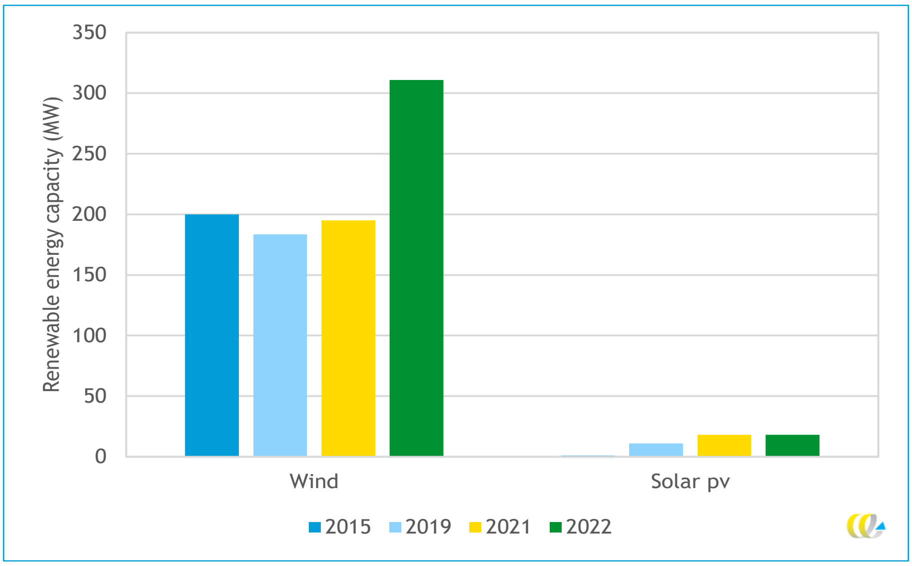
Figure 27 - Renewable energy capacity at North Sea Port



Rotterdam

The Port of Rotterdam produces renewable energy from wind, solar and biomass. The exact capacity of biomass production is not known and therefore not included in Figure 27. At the end of 2022, a new windfarm opened on the second Maasvlakte, which resulted in a large growth in renewable energy production. The capacity of solar energy is growing, but is still limited compared to wind energy.

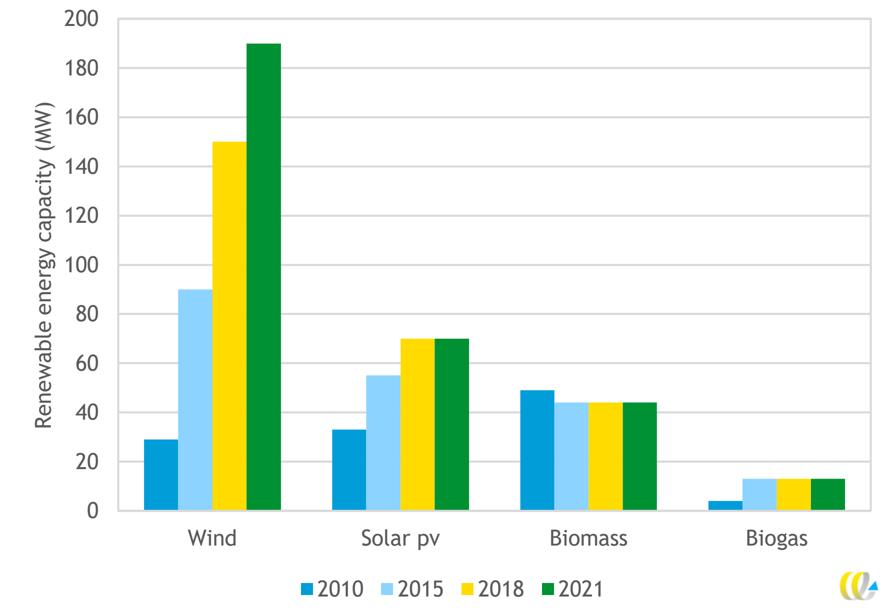
Figure 28 - Renewable energy capacity at Port of Rotterdam



Antwerp

The Port of Antwerp reports on renewable energy capacity of wind, solar biomass and biogas. The results are shown in Figure 28. Since 2010, there has been a significant growth in wind and solar power production capacity. In recent years, the production capacity of biomass and biogas has remained fairly stable.

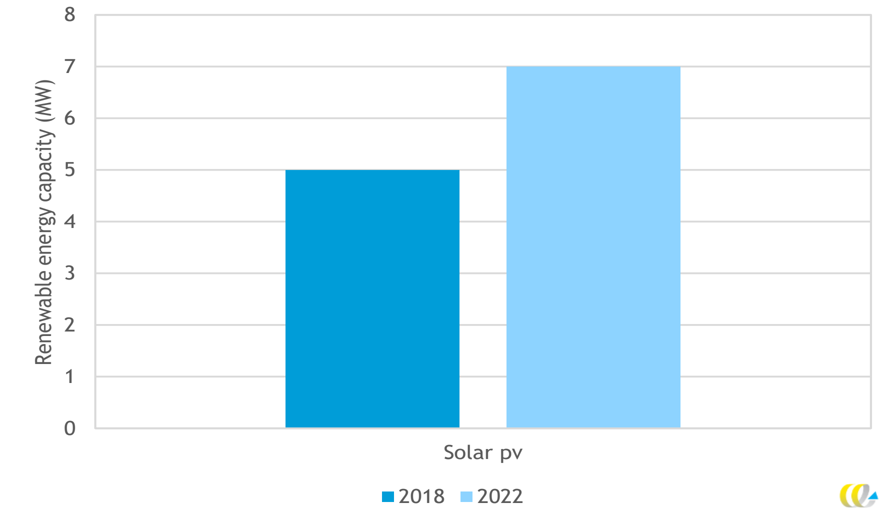
Figure 29 - Renewable energy capacity at Port of Antwerp



Barcelona

The Port of Barcelona reports on renewable energy production capacity from solar power. This increased between 2018 and 2022, as shown in Figure 29.

Figure 30 - Renewable energy capacity at Port of Barcelona



7.2 Biofuels

Other forms of renewable energy are produced in ports besides electricity. These include sustainable gas and transport fuels. Since production is often undertaken by private firms, information on production levels is often not publicly available. Therefore, the results presented in Table 54 are a rough estimate. For other ports no concrete figures were found.

Table 54 - Biofuel production capacity

kton	2021
Amsterdam	100
Groningen	450
North Sea port	655
Rotterdam	1,700

In recent years, many new initiatives have been launched in this field. The increased ambitions for biofuels, as stipulated in the *'Fit for 55'* package, mean that more facilities are expected to be opened. The production figures for biofuels are difficult to record and were not included in the previous edition of the benchmark. A reflection on historical production levels is therefore not included in this edition.

7.3 Conclusions

In order to mitigate climate change, a shift towards renewable energy is required. This chapter has shown that many ports are involved in renewable energy. This mainly involves wind and solar energy, biomass and the production and throughput of biofuels. The information is often not centrally available and the information in this chapter is partly based on less official sources, especially for foreign ports. Reporting of renewable energy capacity could thus be improved. The results indicate that solar panels are increasingly used in port areas. The same applies to wind energy, but the growth here is more incremental due to the completion of new projects. Off-shore wind projects in particular are having a large impact. Recently, new wind farms have been connected to the grid in Dutch ports. In the ports of Le Havre and Hamburg, wind farms are also being constructed in ports.

Ports are also looking into the production and transhipment of renewable energy carriers, such as green hydrogen and biofuels. Green hydrogen initiatives are currently mainly small-scale initiatives. In recent years, these initiatives have increased, but it is not possible to show increased production levels as yet. Biofuel production does seem to be increasing in the Netherlands, but a definitive conclusion cannot be drawn due to insufficient data.

8 Water quality

This chapter discusses water quality in ports. First, we look at the quality of water measured in port areas. The water quality is influenced by emissions outside the port. Therefore, secondly, we look at the emissions to water in port areas.

8.1 Measured water quality in ports

The European Union has introduced the Water Framework Directive in 2000 in order to improve the quality of surface and ground water in the European Union. This introduced a general requirement for ecological protection and a general minimum chemical standard for all surface waters. The specific quality requirements can be found in Annexes of the Framework. In the Netherlands, the results are reported on the website of Waterkwaliteitsportaal.

8.1.1 Results for Dutch ports

Table 55 shows the water quality in Dutch ports according to the Kader Richtlijn Water (KRW) (WFD in English: Water Framework Directive). The scores range from very good (++), good (+), reasonable (+-), insufficient (-) and bad (--). The water quality in port areas is often not very good. Particularly the chemical quality of water is insufficient in Dutch ports. A positive trend is that ecological and physical chemical quality has increased in several ports, while there is no decrease in quality.

Table 55 - Surface water quality in port areas according to KRW

	Ecological quality		Chemical quality		Physical chemical quality	
	2018	2021	2018	2021	2018	2021
Amsterdam	+/-	+/-	-	-	+/-	+
Groningen	-	+/-	-	-	-	-
Moerdijk	-	-	-	-	+	+
North sea port	-	+/-	-	-	--	-
Rotterdam	+/-	+/-	-	-	+/-	+/-

The quality of water in port areas is improving, but further improvements are necessary. As discussed in the national analysis of water quality (Planbureau Voor De Leefomgeving, 2020), this applies to surface water in the Netherlands in general. The most important emissions are nutrients (Nitrogen and Fosfor), crop production products, medicine waste, microplastics and new substances (including PFAS). The main sources of these emissions are agriculture and sewage systems. Microplastics and new substances are emitted by a diffuse number of sources. These emissions sources often lie outside port areas, which exemplifies the fact that water quality in ports is only partly influenced by the ports itself. The next section will look more closely at emissions in port areas.

8.1.2 International ports

water quality is also measured in several international ports, although the systems differ from one port and country to another. The European Framework directive defined European levels of water quality. These results are presented in interactive maps by the EEA. The main results are presented in Table 56. The scores range from very good (++), good (+), reasonable (+-), insufficient (-) and bad (--).

Table 56 - Water quality in European ports according to WFD

	Ecological status	Chemical status	Physical chemical quality
	2020	2020	2020
Antwerp	-	-	+/-
Barcelona	+-	-	-
Bremen	-	-	+/-
Bremerhaven	+/-	+/-	++
Hamburg	+/-	+/-	+/-
Le Havre	-	-	++
London	+/-	+/-	+/-

The port authority of Vancouver mentions on its website that water quality is monitored and measured. There are, however, no results publicly available that can confirm this statement. The ports of Long Beach and Los Angeles have a combined water action plan and water quality is measured regularly. In 2018, all water quality targets were met at four measurement points at the ports, while targets were not met at four measurement points.

8.2 Emissions to water in European port areas.

In Europe, large industrial facilities are often located in the port areas. Industrial areas often house large companies that are required to report emissions to the national government and to the European Union. Sewage treatment plants, which are also located in ports, are also required to report emissions. These companies have permits to release substances to water. Since 1990, the amount of emissions has reduced significantly according to CLO (Compendium Voor De Leefomgeving, 2022). As a result, the annual contribution of industrial facilities towards national totals has dropped below 10% for all substances emitted to surface water. Industrial facilities also emit to the sewage system. Depending on the substance, this increases the contribution to national totals by 1-5%. Sewage treatment systems also emit to surface water. Some substances are difficult to remove from wastewater and as a result end up in surface water. After heavy rain, spillages may also occur at waste treatment centres causing emissions to surface water.

In this chapter a selection of substances have been included because the data is well available and are of relevance for ports. Some substances which are of relevance to ports are not included due to lack of data. PFAS is one of these substances. PFAS are chemical substances not naturally in the environment. The dangers of these substances are not yet fully known and monitoring for these substances is still immature. In the Port of Antwerp PFAS emissions result in additional costs of cleaning ground water[16]. Also in the Netherlands PFAS is resulting in issues in ports[17].

[16] www.tijd.be/politiek-economie/belgie/vlaanderen/pfas-vervuiling-bedreigt-ontwikkeling-antwerpse-haven/10386970.html

[17] www.bndestem.nl/moerdijk/giftig-pfas-vermoedelijk-op-veel-meer-plaatsen-in-brabant~a6b85deb/?referrer=https%3A%2F%2Fwww.google.com%2F

Table 57 provides an overview of the annual emissions of Nitrogen to water in European ports by major emitters. Most of the emissions are due to wastewater treatment facilities that are situated in port areas. Only a small amount of emissions are due to the chemical and energy sectors. Most ports show a stable or decreasing level of emissions. Some noteworthy developments include:

- a new waste treatment plant opened in Le Havre in 2011, which significantly reduced emissions of nitrogen and phosphorus;
- a waste treatment plan in Barcelona shows large annul fluctuations, but with an overall increase in emissions which seems to contradict the general trend of decreases shown in other ports;
- the waste treatment facility in Amsterdam reported no emissions for 2020, resulting in significantly lower emissions.

Table 57 – Annual emissions (kg) of Nitrogen to water

Kg per year	2010	2015	2019	2020
Amsterdam	507	500	731	166
Groningen	-	-	-	-
North Sea	154	165	126	107
Moerdijk	-	-	-	-
Rotterdam	1,211	929	996	984
Antwerp	359	233	215	342
Barcelona	588	3,140	2,390	1,220
Bremen	214	85	n/a	n/a
Hamburg	2,318	1,840	n/a	n/a
Le Havre	1,324	383	294	352
London	18,828	17,241	16,022	n/a

Table 58 provides an overview of annual emissions of Fluorides to water in European ports by major emitters. The main sources of emissions are the chemical industry, the production of metals and waste treatment. Some developments worth mentioning are:

- at the North Sea Port, a metal production facility ceased operations after 2011. As a result, emissions decreased significantly.
- a chemical production facility in Amsterdam has fluctuations in annual emissions. 2020 was a year with above-average emissions.
- a metal production facility in Hamburg had higher emissions after 2010.

Table 58 - Annual emissions (kg) of Fluorides to water

Kg per year	2010	2015	2019	2020
Amsterdam	62	80	93	109
Groningen	5	-	7	-
North Sea	350	61	44	38
Moerdijk	-	-	-	-
Rotterdam	60	106	88	78
Antwerp	157	104	136	132
Barcelona	25	17	18	18
Bremen	-	-	n/a	n/a
Hamburg	181	390	n/a	n/a
Le Havre	-	11	-	2
London	205	187	174	n/a

Table 59 shows the emissions of phosphor at various ports. The major sources of phosphor emissions are mainly waste and water treatment. The chemical industry and energy sector are also important. Some developments worth mentioning:
- annual fluctuations are the result of wastewater treatment;
- the opening of a new wastewater treatment plant in 2011 has led to reduction at Le Havre;
- the wastewater treatment centre in Amsterdam has not reported emissions for 2020.

Table 59 - Annual emissions (kg) of Phosphor to water

Kg per year	2010	2015	2018	2020
Amsterdam	40,400	36,100	92,940	16,840
Groningen	-	-	-	-
North Sea	28,350	7,600	21,080	11,150
Moerdijk	-	-	-	-
Rotterdam	76,330	92,800	78,400	86,900
Antwerp	26,850	27,300	60,740	54,060
Barcelona	259,000	454,000	326,000	-
Bremen	-	-	n/a	n/a
Hamburg	102,000	113,000	n/a	n/a
Le Havre	112,000	18,000	13,600	24,790
London	3,028,500	2,242,900	2,056,664	n/a

Table 60 shows the emissions of Cadmium to water. Important sources of emissions are metal production and waste treatment. The reduction in Le Havre is due to the opening of a new waste treatment centre.

Table 60 - Annual emissions (kg) of Cadmium to water

Kg per year	2010	2015	2019	2020
Amsterdam	-	-	-	-
Groningen	-	-	-	-
North Sea	11	15	12	12
Moerdijk	-	-	-	-
Rotterdam	-	-	-	-
Antwerp	-	-	-	-
Barcelona	-	6	-	-
Bremen	6	-	n/a	n/a
Hamburg	10	-	n/a	n/a
Le Havre	84	34	13	14
London	94	92	72	n/a

Table 61 provides an overview of emissions of Lead to water. The major sources of emissions are metal production and waste and wastewater treatment. Some reasons for the fluctuations:
- a metal producer ceased operating in 2011 at the North Sea Port;
- in Rotterdam, some chemical facilities have irregular emissions of lead. These stopped before 2015;
- in Le Havre, a new water treatment centre opened in 2011;
- in London, emissions of lead due to waste water treatment centres increased after 2013.

Table 61 - Annual emissions (kg) of Lead to water

Kg per year	2010	2015	2019	2020
Amsterdam	23	47	42	-
Groningen	26	31	-	-
North Sea	2,450	548	276	418
Moerdijk	-	-	-	-
Rotterdam	381	46	57	28
Antwerp	-	-	-	-
Barcelona	-	-	211	-
Bremen	-	-	n/a	n/a
Hamburg	55	35	n/a	n/a
Le Havre	606	99	61	53
London	117	880	820	n/a

Table 62 shows the emissions of Zinc to water in port areas. The main sources are waste and waste water, the chemical industry and metal production. Some reasons for the large fluctuations are:

- in Barcelona, a water treatment centre has large annual fluctuations. 2010 was a year with high emissions;
- in Amsterdam, a wastewater treatment centre did not report emissions for 2020;
- in London, wastewater treatment centres have increased emissions since 2010.

Table 62 - Annual emissions (kg) of Zinc to water

Kg per year	2010	2015	2019	2020
Amsterdam	3,270	2,170	2,084	239
Groningen	-	-	-	-
North Sea	4,392	2,892	4,699	5,436
Moerdijk	-	125	173	-
Rotterdam	2,953	1,790	2,335	1,749
Antwerp	2,348	2,810	2,015	1,548
Barcelona	9,132	2,680	2,580	1,820
Bremen	561	328	n/a	n/a
Hamburg	3,449	5,060	n/a	n/a
Le Havre	3,593	2,155	2,777	2,389
London	14,643	35,067	32,643	n/a

Table 63 provides an overview of the emissions of Nickel to water. The main sources are waste and wastewater, the chemical industry, energy production and metal production. The largest fluctuations can be explained by following reasons:

- in 2011 a metal factory ceased production in the North Sea Port;
- in London, emissions are increasing due to wastewater treatment centres;
- in Rotterdam, the chemical industry is emitting less.

Table 63 - Annual emissions (kg) of Nickel to water

Kg per year	2010	2015	2019	2020
Amsterdam	118	138	223	94
Groningen	-	-	-	-

Kg per year	2010	2015	2019	2020
North Sea	791	332	373	381
Moerdijk	-	-	-	-
Rotterdam	1,297	1,069	624	674
Antwerp	349	319	320	458
Barcelona	1,920	1,768	1,987	1,110
Bremen	40	57	n/a	n/a
Hamburg	965	1,025	n/a	n/a
Le Havre	348	803	721	628
London	2,752	4,441	4,094	n/a

Table 64 provides an overview of emissions of Copper to water. Waste and wastewater treatment, the chemical industry and metal production are the main sources of emissions. Some of the explanations for the fluctuations are:
- in Le Havre, one waste treatment centre emitted large quantities of copper in 2019;
- in Amsterdam, a wastewater treatment centre reported no emissions for 2020.

Table 64 - Annual emissions (kg) of Copper to water

Kg per year	2010	2015	2019	2020
Amsterdam	281	405	408	54
Groningen	-	-	-	-
North Sea	204	416	300	341
Moerdijk	53	-	-	-
Rotterdam	528	237	544	420
Antwerp	121	175	-	150
Barcelona	294	560	580	-
Bremen	-	-	n/a	n/a
Hamburg	1,075	1,339	n/a	n/a
Le Havre	839	99	1,097	376
London	11,189	11,219	10,389	n/a

8.3 Conclusions

In this chapter, we have analysed water quality in ports. In Europe, water quality is measured through the Water Framework Directive. This directive, stipulates specific values to score the water quality. The results show that the quality of water is improving, but quite slowly. There is therefore a lot of room for improvement. Improvement must also be made outside the ports. Our analysis shows that the emissions to water in port areas only are small part of the total emissions to water. The main conclusions regarding emissions to water:
- For most substances, emissions in port areas decrease slightly over time.
- PFAS emissions are an important source of pollution. Data availability for these emissions is however insufficient to include in this edition in the benchmark.
- Urban wastewater treatment centres are an important source of emissions. These are largely not directly related to port activities and this affects the results for the ports. In Le Havre, a new treatment centre has led to a significant reduction in annual emissions. Using the latest techniques could reduce emissions further.
- Industrial facilities have fluctuations in annual emission levels, but overall reductions are visible.

9 Maritime waste

Shipping waste is an important source of waste in the North Sea. An analysis of waste on Dutch beaches reveals that 44% comes from marine sources (shipping/fishing), 30% from land (especially from beach tourism), and 26% from unknown sources (Rijksoverheid, 2023). Three quarters of the waste is plastic, both larger pieces of plastic as well as micro plastic. Dealing with litter in catchment basins is an important starting point for reducing the amount of marine litter. In order to mitigate pollution, it is important for ports to have good facilities in place. This chapter focuses on the management of waste in port areas.

The collection of shipping waste from inland waterway and maritime vessels is organised via different systems. The collection, disposal and reception of waste from inland vessels is subject to uniform regulations in the Ship Waste Decree (CDNI). These apply to Germany, Belgium, France, Luxembourg, Switzerland and the Netherlands. In the Netherlands, SAB (Stichting Afvalstoffen & Vaardocumenten Binnenvaart), a national institute, is responsible for the network and financing of waste collection from inland vessels. Waste containing oil and grease, waste from cargo and other commercial waste is collected according to regulations. Waste collection is financed by charging an additional fee on top of fuel costs for each m^3 of fuel bunkered.

The collection of maritime waste is the responsibility of ports as prescribed in Directive (EU) 2019/883. This European Directive aims to ensure that waste generated on ships, and passively fished waste, is not thrown into the sea but returned to land and adequately managed. In broad terms, the Directive makes it mandatory for maritime vessels to return all waste to port facilities. An exception to this rule applies to ships with sufficient capacity to store waste accumulated during their intended voyage until they reach the next port of call. In order to reduce illegal discharge, vessels are required to pay for waste facilities regardless of the amount of waste discharged. Vessels can deposit common types of waste up to their waste capacity on board without additional charge. This reduces the incentive for vessel owners to discharge waste at open sea. A similar system was already in place in the Netherlands and as such no major changes have been made in the Netherlands in recent years.

The various types of waste generated by maritime vessels are defined in various annexes of MARPOL, the International Convention for the Prevention of Pollution from Ships. Ship-generated waste are classified under oily waste (Marpol Annex 1), sewage (Marpol Annex 4) and garbage (Marpol Annex 5). Cargo residues include oily waste (Annex 1) and chemicals (Annex 2) for liquid bulk tanker vessels. Annex VI includes sludge produced by the exhaust gas cleaning system. It is important that ports provide facilities for the various type of waste. We firstly look at port waste facilities in Dutch ports. Secondly, we look at the amount of waste collected at each port.

9.1 Port waste facilities

The ports of Rotterdam and Moerdijk are included in the same area for maritime waste handling. In total, 20 companies are active in waste management in this area. Collection is carried out by vessels, vehicles and deposit tanks. All types of waste, as defined by Marpol Annex I to Vi, can be deposited at the Port of Rotterdam. The charge for waste disposal depends on the Gross Tonnage of vessels. Discounts are available for vessels sailing on cleaner fuels, such as LNG and marine diesel oil. Short sea vessels can also receive a discount of 5%. Vessels that take measures to reduce waste production are eligible for a discount as well(Port of Rotterdam, 2022a).

The Port of Amsterdam also offers waste facilities for all types of waste. The facilities are combined with other ports along the North Sea Canal area. In total, nineteen companies are active in this area. The charges depend on the size of the vessels. Environmentally friendly vessels are powered by marine gas oil, marine diesel oil and LNG. The port pays refunds when actual waste is delivered to encourage the delivery of waste.

At Groningen Seaports, ten companies are active in waste collection covering all types of Maritime waste. The pricing of waste collection depends on the size of the vessels. Vessels that produce less waste are currently not given a discount on waste charges as no uniform European standards currently exist. Environmentally friendly vessels can receive a discount on port charges. Short sea vessels that stay within Europe receive a discount of 20%, as these call at ports more often.

At the North Sea Port, the ports of Terneuzen and Vlissingen are serviced by a single company that collects all types of waste using vessels and vehicles. The charges depend on the size of the vessel. No discounts are mentioned in the waste management report (North Sea Port, 2021b). In Gent, the collection is based on the size of vessels. Discounts are available for short-sea vessels and vessels with sustainable waste management. Gent also works with a system of indirect financing.

In Antwerp, there are thirteen companies collecting waste. Environmentally friendly vessels can receive an annual discount on waste charges. The waste charges depend on the gross tonnage and possibly on the type of vessel, the provision of services outside regular working hours and hazardous waste (Port of Antwerp Bruges, 2022c).

A similar funding system exists in Hamburg. The port has thirteen companies collecting various type of waste. However, no information is available in English. This is also the case for the ports of Bremen, Barcelona and Le Havre.

The Port of Vancouver has a port information guide, which provides very limited information about vessel waste. It is not clear how the funding of waste reception is organised and what efforts are taken to reduce illegal discharges. There is information about accidental spillages at the port. The ports of Los Angeles and Long Beach fall under the Californian Vessel Waste Disposal Plan. However, the document is not accessible.

9.2 Collected waste

The amount of waste collected is measured in the Netherlands. A country wide scheme started in 2005, which can be regarded as the base year. Table 65 shows the proportion of vessels that deposit waste. After 2005, this increased in most ports in the Netherlands. However, there are large fluctuations and as a result it is difficult to draw conclusions. According to one expert, the COVID-19 pandemic had an effect on waste deposal patterns.

Table 65 – Proportion of vessels depositing maritime waste

	2005	2015	2019	2020	2021
Amsterdam	30%	69%	69%	69%	63%
Groningen Seaports	20%	14%	84%	48%	97%
North Sea Port - NL	15%	60%	52%	41%	42%
Rotterdam & Moerdijk	28%	79%	63%	66%	62%

Table 66, Table 67 and Table 68 show the amount of waste collected by depositing vessel by type of waste. Annex 1 type waste includes all oil waste and shows large fluctuations from year to year. A decrease in the amount of waste collected does not immediately indicate any issues. Deposited amounts are affected by outliers that deposit large quantities at one time. Especially in smaller ports, such as the Port of Groningen, this effect can be seen. As waste management facilities in other ports improve, vessels may also opt to use facilities in other ports.

Table 66 - m^3 waste collected by vessel of Annex I type

	2005	2015	2019	2020	2021
Amsterdam	3.4	4.2	2.8	2.8	2.4
Groningen Seaports	4.1	4.1	0.9	2.2	1.0
North Sea Port - NL	5.8	3.2	4.6	4.6	5.5
Rotterdam & Moerdijk	4.2	4.1	5.7	5.4	n/a*

* Results for 2021 for Rotterdam are not included because these are not definitive.

Table 67 - m^3 waste collected by vessel of Annex IV type

	2005	2015	2019	2020	2021
Amsterdam	0.99	0.25	0.04	0.04	0.06
Groningen Seaports	0.00	1.38	0.62	0.98	0.06
North Sea Port - NL	0.00	0.07	0.00	1.04	0.03
Rotterdam & Moerdijk	0.27	0.24	0.30	0.99	n/a*

* Results for 2021 for Rotterdam are not included because these are not definitive.

Table 68 - m^3 waste collected by vessel of Annex V type

	2005	2015	2019	2020	2021
Amsterdam	4.2	4.1	4.3	4.3	3.1
Groningen Seaports	0.5	5.5	3.3	2.6	1.0
North Sea Port - NL	0.7	2.4	1.6	2.1	1.9
Rotterdam & Moerdijk	2.9	3.0	3.9	4.9	n/a*

* Results for 2021 for Rotterdam are not included because these are not definitive.

9.3 Conclusions

Shipping waste is an important source of pollution in oceans. This ranges from oily substances to the so-called ‘plastic soup’ made up of household waste. In order to resolve these issues, adequate waste management facilities have to be in place in ports. The ports studied seem capable of processing the main types of maritime waste. However, further measures could reduce illegal dumping of waste. Illegal dumping can be a financial incentive for vessel owners if the costs of waste discharge are significant. In the Netherlands, and recently in the EU, a system has been introduced where vessels pay a charge regardless of the amount of waste discharged. When actually discharging waste, these vessels receive a discount on the waste charges. As a result, there is an incentive to discharge waste. Similarly, in the Netherlands, there is an incentive programme to deposit waste collected during fishing.

10 Modal split

10.1 Introduction

Goods arriving in seaports can be transported further by various modes of transport. The most common modes of transport are heavy goods vehicles (trucks), inland waterway vessels, trains, pipelines and short sea shipping[18]. Certain modes of transport are more environmentally efficient than others, and transport using these modalities is preferred whenever possible.

Transport modalities

In general pipelines are a safe and sustainable form of transport for liquid bulk, such as oil products, chemicals and industrial gasses. Various pipeline networks are available in Europe that connect major industries, including chemical industries. Pipelines are specially built for certain types of goods; it is not possible to transport all types of liquid bulk through the same pipeline due to contamination issues. The ability to operate pipelines therefore relies on consistent transport volumes of sufficient size. In other words, pipeline transport is only suitable for specific goods and locations. The same applies to a certain extent for inland waterway transport and rail transport, as destinations must be accessible by river or rail. All five Dutch seaports are accessible by railways and inland waterways. The road network is very dense and almost all goods can be transported by heavy goods vehicles. Unfortunately, road transport is often not the most sustainable option.

10.2 Results ports

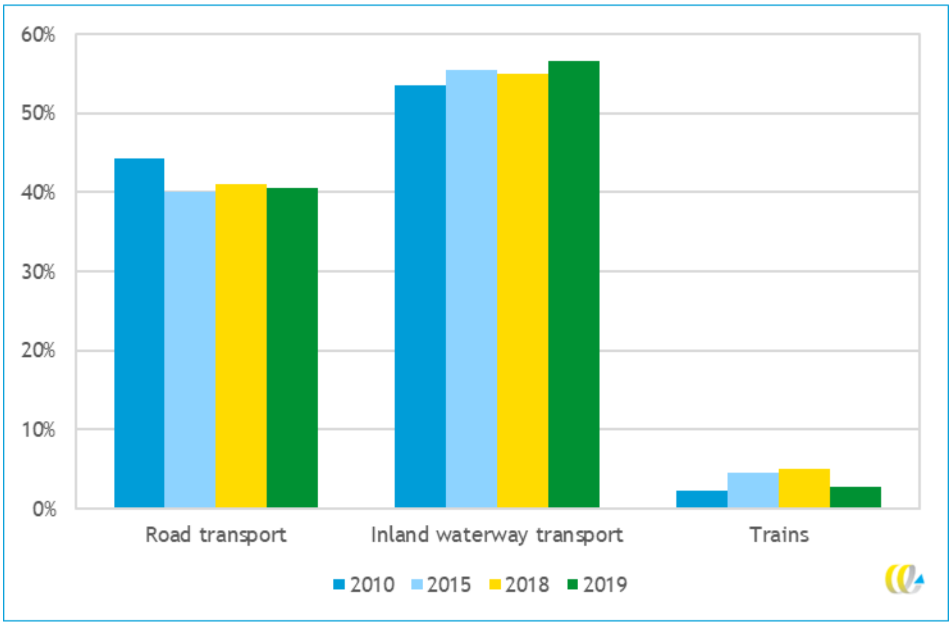
The modal split results are submitted by multiple ports. These ports will be discussed in this chapter. The ports of Groningen, London, Long Beach and Vancouver do not report information on modal shares.

Port of Amsterdam

The transport flows are known for the greater Amsterdam North Sea Canal area. Transport flows via pipelines and short sea shipping are not included in the results. The results show that since 2010, the proportion of road transport has decreased and the proportion of inland waterway transport has increased slightly. The amount of rail transport varies from year to year and decreased from 2018 to 2019. The Port of Amsterdam (Port of Amsterdam, 2020b) aims to improve the modal split further towards 2050 by removing barriers to inland shipping, collaborating with other ports and more high frequency train routes.

[18] 'Short sea shipping' is the movement of cargo and passengers by sea over short distance where no ocean is crossed.

Figure 31 - Modal split of the Port of Amsterdam



Port of Moerdijk

Similar to Groningen Seaports, the Port of Moerdijk also does not publicise modal split numbers. Table 69 shows the number of inland vessels and trains that visited the Port of Moerdijk between 2015 and 2018. Between 2015 and 2018, all modes of transport have increased, but rail transport increased relatively the most (by almost 66%). This could indicate a relative decrease in road transport, but because we do not have those figures, we cannot be certain.

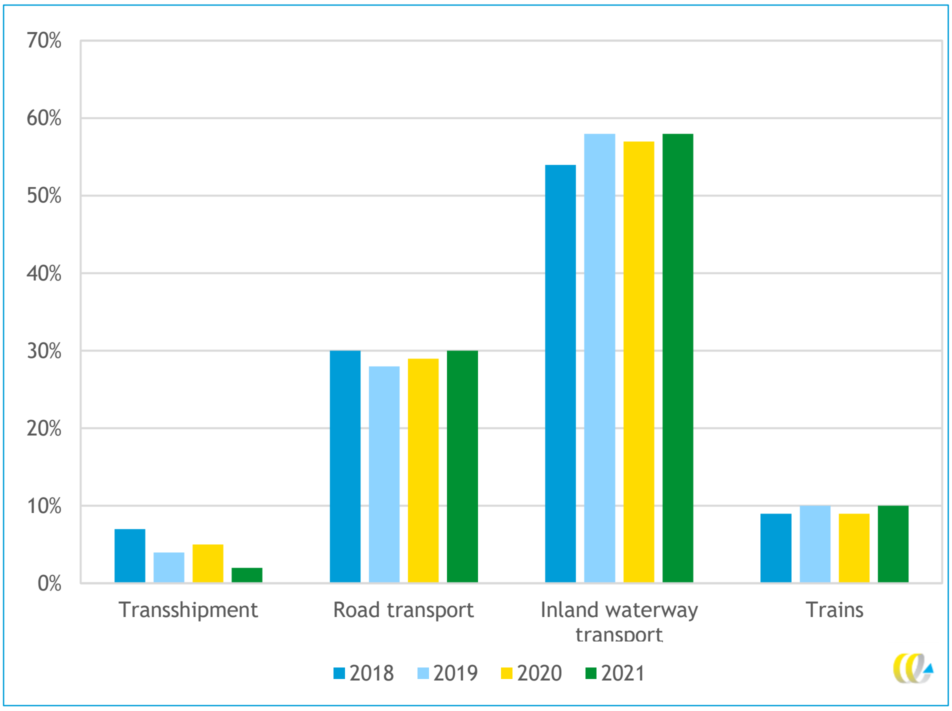
Table 69 - Number of inland vessels and trains visiting the Port of Moerdijk

Number of visits	2015	2016	2017	2018
Inland vessels	10,974	11,383	11,734	12,183
Trains	1,810	1,990	2,790	3,000
Short sea vessels	1,769	1,900	2.059	2,136

North Sea Port

The modal split of the North Sea Port is visible in Figure 31. The North Sea Port uses pipelines, but they are not included in the modal split figures. The table shows that all figures are remaining somewhat at the same level and there is not really a discernible pattern. All transport modes show a different trend in 2021 compared to 2019. The North Sea Port states on its website that it is pursuing a modal shift towards rail, inland waterway transport and pipelines because of their more efficient CO_2 emissions. This shift is yet not visible in the modal split figures. The volume of bulk that is being transported through pipelines is being estimated on around 15 to 16 million tonnes yearly.

Figure 32 - Modal split of the North Sea Port



Rotterdam

The modal split for Rotterdam is displayed in Table 70. Rotterdam does not include the proportion of short sea shipping in its results. The figures depicting the results also do not include pipeline transport. We can see that the proportion of road and rail transport is declining, and the proportion of inland waterway transport is increasing over time. This is a good environmental shift, as road transport is the dirtiest way of transporting goods to the hinterland from an environmental point of view.

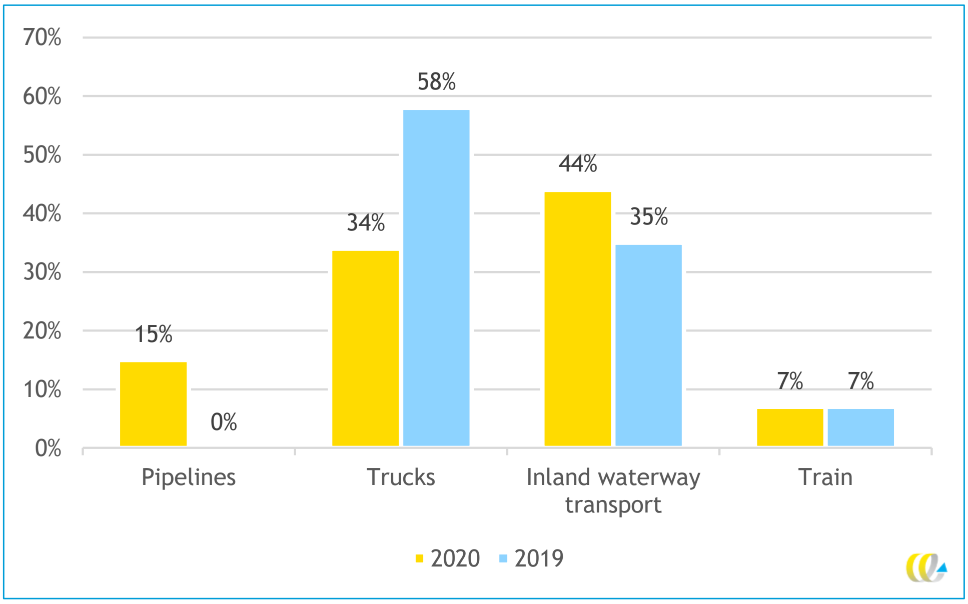
Table 70 - modal split for container transport at Port of Rotterdam

	2018	2019	2020
Road transport	58.0%	56.0%	52.0%
Inland waterway transport	30.0%	33.0%	38.0%
Trains	12.0%	11.0%	10.0%

Antwerp

The Port of Antwerp is accessible by rail, road and inland waterways. Furthermore, Antwerp has several pipeline connections to other regions in North Europe. Figure 32 shows the modal split for the Port of Antwerp in 2019 and 2020. The modal split for other years is not available in a similar range. In 2020, the majority of goods are transported by inland river barges and trucks. The proportion of pipelines and trains is significantly lower. Due to the lack of results over time, it is not possible to draw conclusions on the development of the modal split.

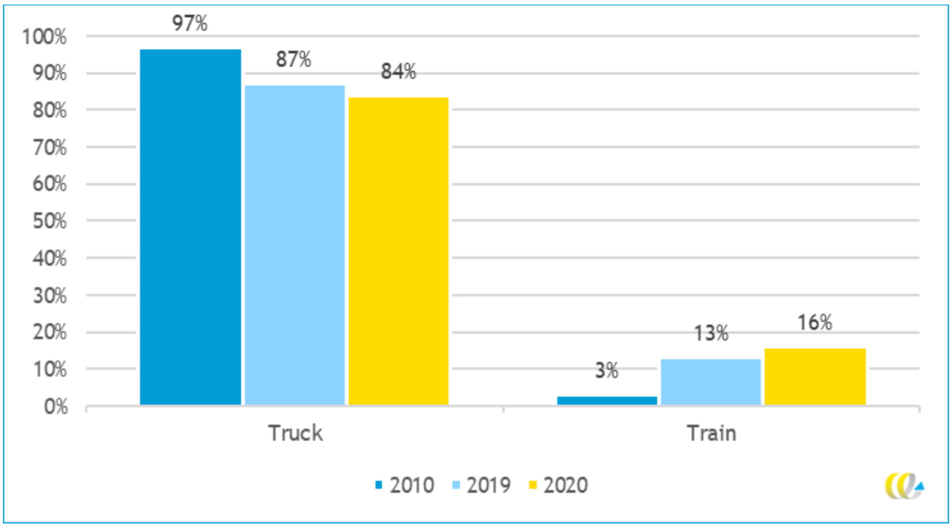
Figure 33 - Modal split Antwerp



Barcelona

The Port of Barcelona is not situated along an navigable inland river. As there is no major industrial complex, pipeline transport is negligible. The modal share therefore consists of truck and rail transport. Due to negative externalities of trucking, specifically congestion and air pollution, the Port of Barcelona promotes the use of trains. Since 2010, a proportion of long-distance transport has shifted to trains. The Port of Barcelona is also pursuing a switch to shorter distances. In 2020, a higher proportion of goods was transported by rail compared to 2019. As results are only available for two years, it is not possible to say whether this development is a trend.

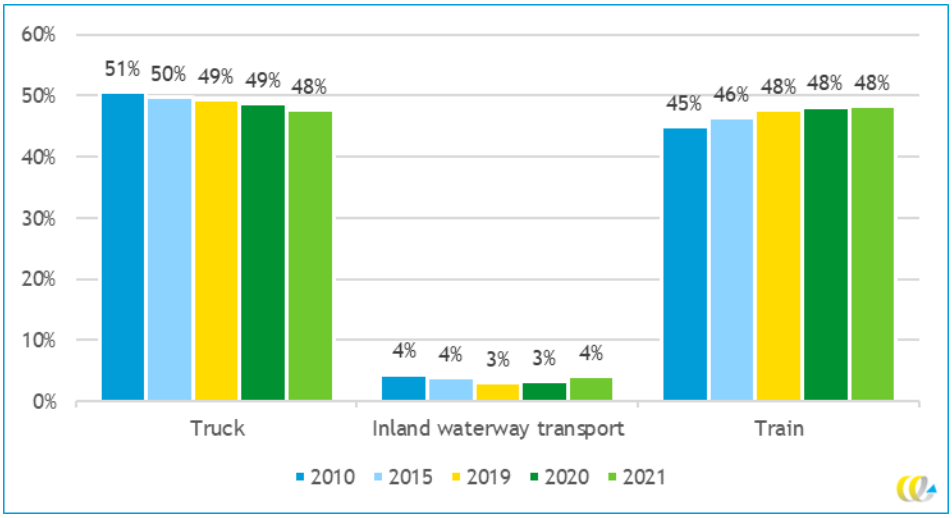
Figure 34 - Modal split Barcelona



Bremen ports

The ports of Bremen are accessible by road, rail and inland waterways. However, the inland waterways are not accessible by the largest vessels. Germany has a very well-developed network of freight rail connections. This is exemplified by the results in Figure 34. Between 2010 and 2021, relatively fewer trucks were used for hinterland transport of goods in favour of trains. The proportion of inland waterway transport is small and fairly constant over time.

Figure 35 - Modal split Bremen ports



Hamburg

The Port of Hamburg is situated along the Elbe river, which can be navigated by inland vessels. However, the river is unlike the ports of Bremen: the most important transport modes are road and railways. In Figure 35, a shift in hinterland container transport is visible from road and rail. This shift is also visible in the modal split of all cargo streams, as shown in Figure 36. However, the proportion of inland waterway cargo also decreased relatively from 2015 to 2022.

Figure 36 - Modal split (in TEU) Port of Hamburg

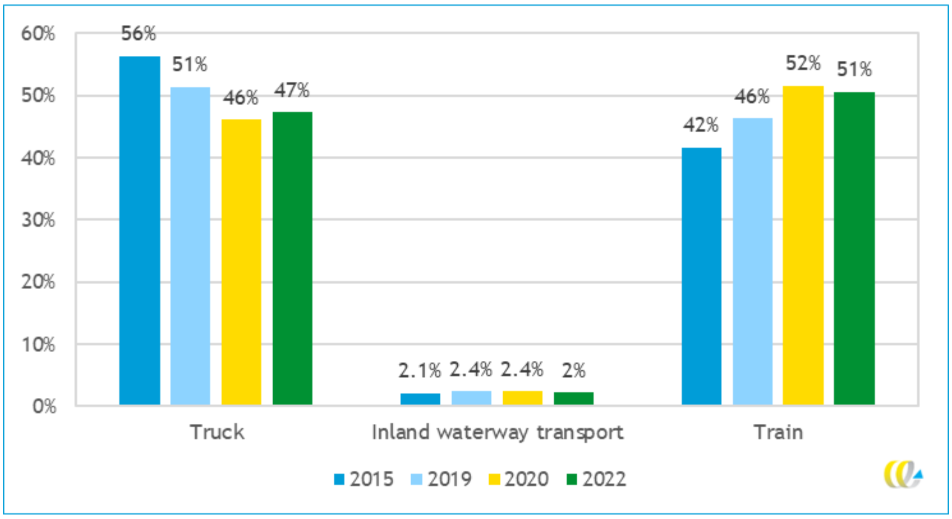
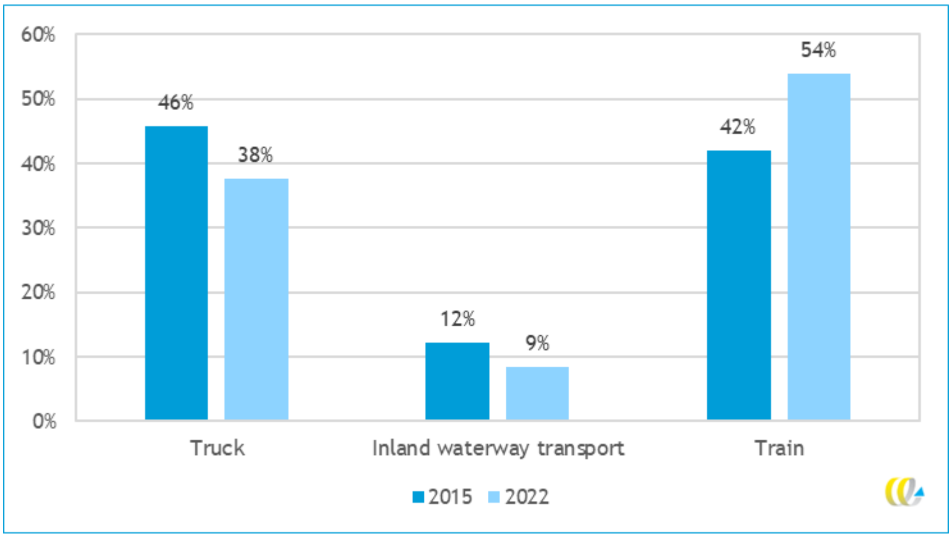


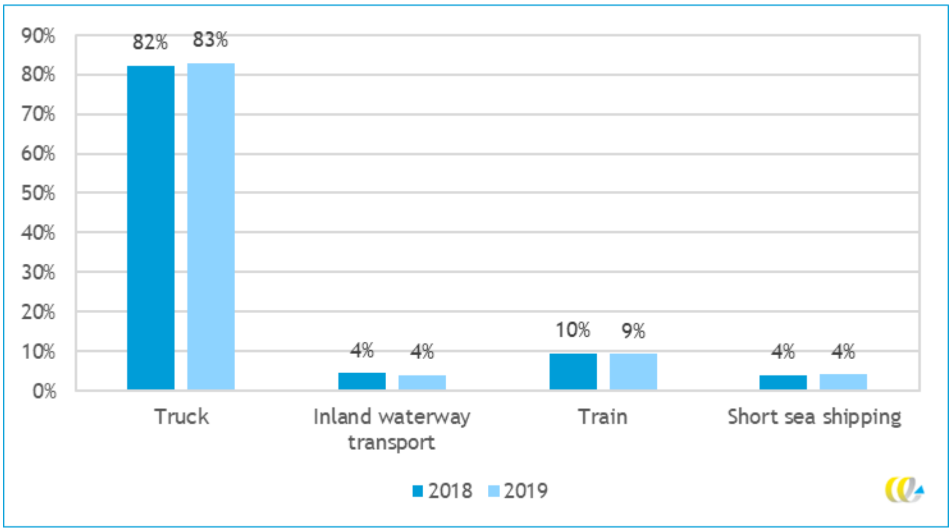
Figure 37 - Modal split (in tonne) Port of Hamburg



Le Havre

The Port of Le Havre is situated at the inlet of the Seine river, which connects Le Havre to the greater Paris area. The port is also accessible by rail and road. Most containers are transported from the Port of Le Havre by truck. Smaller quantities of containers are transported by vessel and train.

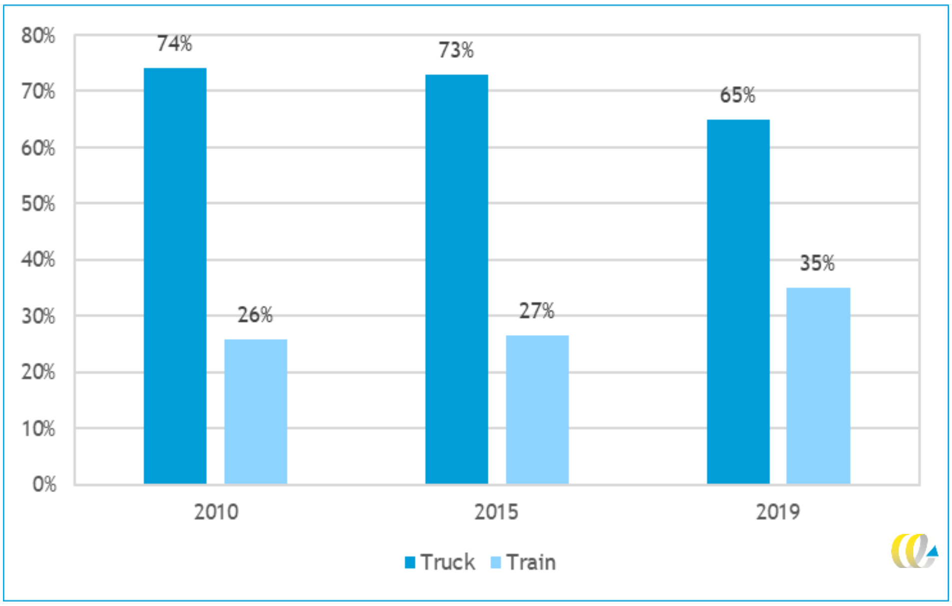
Figure 38 - Modal split containers Port of Le Havre



Los Angeles

The Port of Los Angeles is situated in one of the most densely populated areas in the United States. In order to avoid congestion by trucks, the port is investing in railway transport. Between 2010 and 2019, a higher proportion of goods were transported by train and relatively fewer goods were transported by truck.

Figure 39 - Modal split containers Port of Los Angeles



10.3 Conclusions

Hinterland options are determined to some extent by the location and the characteristics of the port. Heavy goods are most suited to be transported by pipelines, rail and inland waterways. Containers are multifunctional and can be transported by all modes except, of course, pipelines. Ports are still able to influence transport decisions given the background of the port. For example, investing in railway infrastructure can increase the proportion of train transport. Many ports mention on their website or in their sustainability reports the importance of improving the modal share. In this chapter, we have combined recent results with findings from the previous edition, where available. By doing so, we can see whether modal shares are improving, which is primarily visible in the long-term. The ports of Bremen, Hamburg and Los Angeles show that improvements in modal shares is possible in the long-term.

11 Community relations

11.1 Introduction

Ports important workplaces for many people. At the same time, port activities can inconvenience nearby urban locations. Good relations with local communities are therefore an important aspect of a sustainable port. In this chapter, we discuss a selection of measures taken by various ports.

11.2 Results for ports

Amsterdam

It is important for the Port of Amsterdam to engage with local residents about port activities. Much of the communication takes place via social media. When necessary, there will be quarterly monitoring meetings with residents of quays who experience inconvenience from river cruises and inland shipping. The Port of Amsterdam aims to manage expectations and create mutual understanding. A clean-up campaign is organised every year together with employees of the port area. Various events, such as a port exhibition in the National Maritime Museum and interviews regarding major port-related projects, are organised to give the public insight into projects and port activities. The Port of Amsterdam hosts the 'Zeehavendagen' (sea port days) every year. During this event that takes 4 days, visitors can learn more about port related activities of businesses located in the port area, workshops and activities that tell about the past of the port. The event is also used to connect education and the job market to the vacancies within the port area.

Groningen

Groningen Seaports actively informs local residents about the progress of developments in the port area, and about special projects in the industrial areas. Due to the COVID-19 pandemic, it was not possible to host an informative meeting for local residents, which usually takes place once per year (it did not take place in 2020 and 2021). Local residents were informed via the newsletter that is distributed three times a year.

Moerdijk

The Port of Moerdijk tries to encourage dialogue with local residents through newsletters, the media, including social media, 'omgevingstafels' (discussions between local residents, companies, municipalities and the port authority about activities in the industrial and port area). A good example is Appelzak-Zuid, a new nature area that compensates for port and industrial activities, based on a design and ideas from local residents to create a green space.

Rotterdam

The Port of Rotterdam puts a lot of effort into maintaining good relations with local residents and stakeholders. Odour complaints steadily decreased from 2016 to 2018.
In 2019, however, complaints increased by about 15%. The port uses many ways to keep its neighbours and others in the vicinity of the port informed. Some examples include a port newspaper (issued four times a year), informative meetings (on a project basis), World Port Days (three days per year), focus groups with local residents (two or three times a year), receptions for groups at the World Port Centre and in the port (x100x a year), webcare/social media that is updated daily and an information centre called Futureland with more than 100,000 annual visitors. An analysis to the reputation of the port among residents is conducted once every two years. In 2017, the port scored 80.9 points out of 100. In 2019, this increased to 86.6 and in 2021, the score was 83.2. From 2016 to 2021, there were two major incidents.

North Sea Port

The motto of the North Sea Port on community relations is ‘staying in contact’, looking out for each other’s interests and seeking consensus. The North Sea Port wants to act as a connector and create a close-knit port community. Core values of the North Sea Port are community building, respect and future-proofing.

Antwerp

The Port of Antwerp has designed a specific part of its website for neighbouring communities. This includes information about air quality and odour pollution, and it provides a portal to report noise and odour pollution to the port. Other topics include cycling and especially the option of taking bikes on ferries and buses. It is noteworthy that companies in the port hold an annual clean-up, where litter is collected throughout the port.

Barcelona

The Port of Barcelona does not provide a section in English about community relations on its website.

Bremen ports

The Port of Bremen addresses cooperation with the local population in its sustainability report. The following issues are mentioned:

- The local public can access the ports by means of guided tours or during open days of companies. There are also several vantage points.
- Noise complaints are monitored and action has been taken in specific areas. A noise map at 5-year intervals is also being developed.
- Transport causes issues for local communities due to congestion and noise.
- Cooperation with local residents is also mentioned. This includes cooperation with a school in a problematic urban district and assistance for flood victims.

Hamburg

The Port of Hamburg devotes attention to local communities in its annual sustainability report. In 2019 and 2020, the port authority gave employees 720 hours off so that they could help by harvesting fruit, volunteering with the conservation charity NABU and gardening. The port authority also plays an active role in society by coordinating donations of food by shipping lines to Hamburg's food banks. In order to reduce the impact of externalities, measures are being taken to improve transport management and promote the use of quieter vehicles.

Le Havre

For visitors, the Port of Le Havre has a port centre which explains the ins and outs of the port. It is also possible to take a guided bus tour of the port or a vessel. No additional information is provided in English.

London

The port authority of London dedicates several sections of its website to local communities. These include public meetings and tidal news. A specific section is dedicated to safety as the Thames is used by various stakeholders, including for leisure activities and sport. Telephone lines are available for urgent issues, such as collisions and pollution. The website includes a reference to the London Port Health Authority in order to make complaints about noise, among other issues.

Los Angeles

The Port of Los Angeles has a specific section of its website dedicated to the community. This includes information for residents and boaters. The Port of Los Angeles also has its own local police that can be contacted directly. The port is located next to the city, which makes community relations extra important. The Port of Los Angeles employs two community affairs advocates who work as liaisons between various communities around the port and the harbour. Further developments include community centres, parks and a basketball field.

Long Beach

The Port of Long Beach dedicated a section of its website to the community. Several programmes are discussed, including education programmes, harbour tours, community grants and sponsorships. Education involves high school internships, scholarship sponsoring as wells as career opportunities. Investments in local projects are quite significant, with almost $ 50 million over the next fifteen years. Funding is going towards community health and the improvement of facilities and infrastructure. Improvement of local neighbourhoods includes introducing energy-efficiency improvements, such as solar panels.

Vancouver

The Port of Vancouver has a dedicated section on its website. Specific attention is given to indigenous relations. A local community centre has been set up where community members can gather for a host of interactive events. The port has four community committees that include various stakeholders. The port devotes up to one per cent of its net income to community investment initiatives. A further aspect is that the port provides educational services, including field trips.

11.3 Conclusions

Ports take various measures to improve community relations. The efforts depend on the size of the port and its proximity to urban areas.

- The ports in Los Angeles and Long Beach are located very close to urban areas. They put considerable effort into programmes, including investment programmes to improve these local neighbourhoods. Air quality is also a very important pillar for these ports.
- The London Port Authority pays special attention to leisure and sport activities that take place on waters regulated by the port. This is an unique feature not discussed by other ports.
- Open days help explain port activities to the general public. The ports of Rotterdam and Bremen, among others, organise such days.
- Many of the port facilitate the reporting of nuisance. Several ports measure such nuisance and try to identify the source in order to reduce the nuisance.
- As the characteristics of the ports differ, so do the focus points of the various ports. Overall, there are many good examples to be found of good community relations among the selected ports.

12 Sustainable strategy

12.1 Introduction

Port authorities often have no immediate influence on the companies situated in the port area. However, port authorities can develop long-term strategies, attract new business areas and reduce reliance on fossil fuels. In this chapter, we present a multi-criteria analysis of the sustainable strategies developed by port authorities in the various ports. This multi-criteria analysis examines the extent to which the sustainable strategies are suitable to adapt to various sustainable themes and future developments. We have selected four important trends for our analysis:

1. Climate change.
2. Energy transition.
3. Digitalisation.
4. Economic trends and geopolitical shift.

For each port, we assess the extent to which the trends are addressed and whether specific targets are set.

12.2 Results

Amsterdam

In 2020, the Municipality of Amsterdam created the updated ‘Municipal port vision’ (Gemeente Amsterdam, 2020). At the moment, the Port of Amsterdam is a bulk port, mainly focusing on the storage and transit of fossil fuels. The roadmap AKN (Amsterdam Klimaatneutraal, Amsterdam Climate Neutral) aims to reduce the CO_2 emissions of Amsterdam by 55% in 2030 compared to 1990, on the way to full climate neutrality by 2050. The phasing out of fossil fuels must go hand in hand with the phasing in of renewable energy carriers. The port has the goal of becoming a key location in the Amsterdam Metropolitan Area and the Netherlands, where a sustainable energy and raw materials system will be realised. The transition towards sustainable energy sources will be an important development, as a large share of current cargo flows consist of fossil fuels. Digitization and scaling up will lead to more efficient and cheaper transport with fewer emissions. The location on the North Sea offers opportunities, as it is ideally suited for large-scale offshore wind energy generation and storage of CO_2 in empty natural gas fields. There also is a shift from transport by road to transport by water and rail for sustainability reasons. In the context of ‘Strategy Amsterdam Circular’, the Port Authority is asked to contribute to an innovative ecosystem for the circular economy, which encourages existing port companies to develop towards circularity and attracts new companies that benefit the circular economy. This trend will lead to flows of goods being more locally and regionally oriented in the future.

The port strategy ‘taking the lead’ (Port of Amsterdam, 2021) consists of many targets, but they are not very specific. These targets include no new coal and oil terminals in the port, more commitment to developing (bio)LNG bunkering capacity, circularity will be encouraged and the generation and storage capacity of renewable energy sources will be increased. We can already see that many of the targets are being reached, such as the recovery of phosphorus from sewage for fertilizer production and research into the possibilities of creating Bio-LNG from waste. Many companies make use of residual flows in the area for resources. The municipal port vision gives a more specific picture. It makes it clear that the port wants to invest in sustainability (fewer fossil fuels, carbon capture/usage, etc.), more circularity (closing the loops), moving towards a green hydrogen economy and becoming an energy hub. There are also two maps depicting the outlook of the 'Amsterdam Hydroport' between 2020-2050. It provides quite a detailed roadmap on how to reach this point by 2050, including a lot of investments in hydrogen technology and synthetic methanol production.

Table 71 - Multi-criteria analysis Port of Amsterdam

Topic	Coverage
Climate change	In order to mitigate climate emissions, the port is planning to make greater use of residual heat, CCS and (green) hydrogen in the future. Greater use of shore power supply will also reduce shipping emissions. A reduction target for 10% CO_2 emissions has been set for 2025. This includes emissions from port industry, shipping and the Port of Amsterdam itself.
Energy transition	The Port of Amsterdam currently has a high share of fossil fuel throughput but this will change in the future. No new grounds will be provided for coal and oil terminals, there will be more commitment to the development of (bio)LNG bunkering capacity, circularity will be encouraged, the generation and storage capacity of renewable energy sources will be expanded to 100 MW, etc. Clear targets are included for 2025. These include: – growth of circular activities by allocating 25 hectares of ground; – 12.5% of fuels will be alternative fuels.
Digitalisation	The port vision of Amsterdam gives some attention to digitalisation: targets include digitalizing administrative shipping processes. It also shares two digital platforms with the Port of Rotterdam: a platform (Portbase) and a management system (Hamis). No specific short term goals are set.
Economic trends and geopolitical shift	The Port of Amsterdam recognises the changes in global dynamics. Especially after the COVID-19 pandemic, there is more room for protectionism and local production. As a result, trade within Europe will become more important, although global trade will remain relevant. However, no specific goals are set.

Groningen

The most recent available vision of Groningen Seaports is the website they have dedicated to this subject (Groningen Seaports, n.d.-b) and the 'Vestigingsbeleid Eemshaven/Delfzijl' (Location policy Eemshaven/Delfzijl) (Groningen Seaports, 2016). According to the website, the Eemsdelta will become the main sustainable port and industrial area in the Northern Netherlands. The energy and data sector in Eemshaven will be of international importance. The chemical and recycling industry in Delfzijl will become completely biobased. This synergy will culminate in an efficient and competitive green port complex. Sustainable economic growth is the best basis in the long run, because sustainability is a requirement for creating added value and employment in the region. Groningen Seaports acts as initiator, facilitator and stimulator in the conviction that green economic growth is sustainable economic growth, which benefits the entire region. Groningen Seaports has a list of activities it focuses on, including 100% sustainable procurement and social returns, use of 100% renewable energy, realization of LNG bunker capacity and shore power connections, etc. The location policy report is mainly focused on new locations and expansions for companies, and which ecological/social frameworks encourage sustainable business, such as re-using residual water, cradle to cradle, facilitating construction and development of wind turbines, spatial zoning based on environmental categories and natural values to strike a balance between economy and ecology. While many of the targets and values are really important to become a sustainable port and industrial area, many of them are rather vague. For example, there are no clear goals that should be achieved by 2030.

Table 72 - Multi-criteria analysis Groningen Seaports

Topic	Coverage
Climate change	Groningen Seaports wants the Eemsdelta to become the most important green port and industrial area in the northern part of The Netherlands by 2030. The chemical and recycling industry in Delfzijl will be entirely biobased. A circular economy and cradle to cradle at area level will lead to lower costs, better environmental performance and greater competitiveness for companies based there. More stringent environmental rules and regulations will also contribute towards this goal.
Energy transition	More effort will be made towards becoming a circular economy and industry will become more biobased. Regional accessibility will improve in the future and there will be more investment in wind farms. There will also be more investment with the goal of attracting logistics flows in collaboration with carriers, shippers, etc. More effort will be put into encouraging cleaner shipping by realizing shore power, LNG bunkering capacity and incentives on port charges.
Digitalisation	Not much is mentioned about digitalisation. The goal for Eemshaven is to become a major Energy and Dataport of international importance. Knowledge will play an important role in the long-term sustainability vision. Knowledge and educational institutes and highly skilled people are abundant in the region. This knowledge must be utilised to strengthen the port and industry area and make it more sustainable.
Economic trends and geopolitical shift	To become one of the most sustainable ports in Europe, the port will offer opportunities to entrepreneurs that value sustainability. Because the port is located close to an international hub of data cables and exchanges, where the mega-capacity trans-Atlantic cables enter Europe from the United States, there are good opportunities for Groningen Seaports to extend its data sector.

Moerdijk

The Moerdijk Port Strategy 2030 was presented in 2014 by the province of North-Brabant and Port Authority Moerdijk, and describes the future plans for Moerdijk port and Industrial Estate until 2030 (Port of Moerdijk, 2014). One of the three main starting points of the Port of Moerdijk is the 'Triple P', which stands for People, Planet and Profit. Sustainable development needs a balanced development process, aimed at enhancing the resilience and quality of nature, the physical and mental wellbeing of the inhabitants and healthy economic development. The creation of value, sustainability and safety play an important role. Both governments and businesses will strive for sustainability and CO_2 reduction, which offers opportunities for renewable energy, energy connections with other industries in the area, and recycling and re-use of raw materials and semi-finished products. In 2030, Moerdijk will be an attractive location for high-quality logistics service providers and manufacturers within the chemical and process industries. The Port of Moerdijk connects the network chains of Rotterdam and Antwerp on the one hand, and the other ports and logistic hubs within the Flemish Dutch Delta on the other hand. The limited draught (vertical distance between the waterline and the bottom of the vessel) is not sufficient for large seagoing vessels, which means that it is difficult to compete with ports like Rotterdam, Antwerp and the North Sea Port, which have higher draughts. Moerdijk will have to specialise in transport by inland vessels and vessel types that rely less on draught.

The port vision of Moerdijk makes it clear that it is committed to a more sustainable economy, greener energy supply, sustainable mobility and more circularity with the goal of becoming more climate resilient and remaining a competitive port. No specific goals are defined in the port vision. The port area and companies are striving for sustainability and CO_2 reduction, and solar energy, biomass and geothermal heat offer great opportunities for the Port of Moerdijk. However, it is not specified to which extent these opportunities will be addressed.

Table 73 - Multi-criteria analysis Port of Moerdijk

Topic	Coverage
Climate change	The Port of Moerdijk wants to become more climate resilient and resistant to extreme weather and sea level rise. Through two programmes, the Port of Moerdijk wants to make the delta area more climate resilient: these are the various delta decisions that are being prepared within the Delta Programme and the National Structural Vision Volkerak-Grevelingen. Particular matter, SO_x, NO_x and CO_2 emissions must remain within the preconditions. This offers opportunities for renewable energy generation. Solar energy, biomass and geothermal heat will offer opportunities to limit emissions and increase safety for people near/within the port area. There are no clear goals, except for the possibility of the port and industrial area becoming an energy-neutral port by 2030.
Energy transition	The Port of Moerdijk wants to realise ecological benefits by drastically reducing the use of fossil fuels. R3 (reduce, re-use and recycle) will become more important due to rising prices for fossil fuels and the increasing scarcity of earth metals. An important aspect in the port's innovative way of licensing is the effective use of physical space and environmental space.
Digitalisation	There are no clear digitalisation goals. Automation of processes and handling of logistics systems will solve the labour shortage and may increase the attractiveness of working in the port and industrial area. Information must be shared to be valuable. Moerdijk must be connected to the port information systems of Rotterdam and Flanders.
Economic trends and geopolitical shift	Scarcity of raw materials leads to opportunities for the Port of Moerdijk, namely 'urban mining', which includes the transhipment and handling of high-quality developed residual materials. Around 2030, Moerdijk hopes to specialise more in consumption and capital flows from Europe to Asia, and in recycling flows. Due to its limited draught, opportunities are likely to revolve around regular, high frequency connections via inland shipping to the three main ports.

North Sea Port

The environmental ambitions of the port region for 2030 are set out in the 'duurzaamheidsambitie 2030', which was drawn up in 2019 in cooperation with the port industry, the province, the local environmental agency and the environmental NGO 'Zeeuwse milieufederatie' (North Sea Port, 2019). North Sea Port is striving to reduce its CO_2 emissions by 40% by 2030, compared to 2005. With a decrease of 35.5% of CO_2 emissions, the goal has not yet been achieved, but the port has realised a substantial reduction even in times of strong economic growth. To reduce the environmental impact of planned pipelines and railway connections, various key performance indicators have been constructed to measure the ambitions. These include improvement of air quality (PM and NO_x), levels of biobased production and 40% CO_2 reduction in 2030. In 2021, North Sea Port announced its new strategic plan to remain a leading European port. This includes three core tasks, consisting of: offering infrastructure and space, nautical services and being the connector in the port area. There are also eight strategic programmes: investing in circular value chains, investing in (clean) energy projects, investing in climate, strong logistics chains, future-proof infrastructure (mainly replaced or new pipelines), digitization and data community, collaborating with the surroundings and being the connector of cooperating parties. North Sea Port has quite specific goals: 15% of raw materials being biobased and 5-10% of raw materials being post-use production by 2030. The North Sea Port industry is striving to reduce CO_2 emissions by 40% by 2030, compared to 2005. In 2019, a reduction of 35.5% was achieved, which means the port area is well on its way. Due to North Sea Port pledge to invest more in transport and storage of CO_2 (CCS and CCU), it is highly likely to reach its sustainability goals if the planned projects are implemented.

The shareholders of the North Sea Port have also published the 'Aandeelhoudersstrategie' (shareholder strategy), which focuses mainly on the balance between sustainability and climate, financial performance and economic development (North Sea Port, 2021a). For any strategic project, the risks should be assessed based on the domains mentioned earlier. North Sea Port should take a supporting, facilitating and a guiding role in the transition to sustainability. Circular economy is also an important theme.

Table 74 - Multi-criteria analysis North Sea Port

Topic	Coverage
Climate change	Reducing annual CO_2 emissions and realise the transition to a climate-neutral industry by 2050 will require significant investment in green hydrogen, sustainable electricity and in new or existing pipelines. North Sea Port will collaborate with Rotterdam and Antwerp on transport and storage of CO_2. A collaborative project is currently under way at the North Sea Port to remove CO and CO_2 from the gases produced during steel making. The possibilities of creating hydrogen through electrolyse are being investigated by the port as well. Clear goals have been set regarding CO_2 reduction.
Energy transition	Bio-based raw materials can replace oil-based raw materials. The port area thinks it is important to make materials as circular as possible, to avoid unnecessary new production and emissions. Projects are analysed in which combustion gases are processed into valuable product flows. The port area will need to optimise the mix of activities within the limited area. Sustainable infrastructure and co-operation with industry and logistics give North Sea Port a supportive and facilitating role. Goals based on raw material usage have been published.
Digitalisation	Digitalisation will strengthen the competitiveness of the port, and contribute to a more sustainable port. A tech cluster is being realised in Ghent to encourage companies working in the maritime sector in the field of innovation and digitization. Smart data will drive logistics chains together with people. One goal is to realise the 'North Sea Portal', which promotes secure and fast data exchange. The port's own management system will also be fully digitised.
Economic trends and geopolitical shift	North Sea Port needs to take a central position in the regional, national and European market. To achieve this, the port wants to co-operate intensively with other companies, as well as with other ports, such as Rotterdam and Antwerp.

Rotterdam

The Rotterdam port vision was published in 2011 and describes the port's vision until 2030 (Port of Rotterdam, 2011). In 2019, a new version was released by the Port of Rotterdam which replaced the original version (Port of Rotterdam, 2019). This was necessary due to newly defined climate goals, etc. The goal is to preserve and increase the social-cultural and economic value of the port complex and to reduce unwanted external effects, such as CO_2 emissions. The Dutch Climate Agreement agreed to reduce CO_2 emissions by 49% by 2030, compared to 1990. The port area needs to be future-proof. Four important developments are: digital innovation (supports prosperity and progress), energy transition (complying with the Dutch Climate Agreement and ceasing gas production in Groningen), raw materials transition (stricter CO_2 ambitions and higher raw material demand leads to a need for circularity and recycling) and changing trade flows (change of economic centre of gravity and certain trade barriers). The Port of Rotterdam has created a three step approach towards a carbon neutral future. Step one focuses on efficiency and development of infrastructure and CCUS. Step two is the switch to a new energy system, including for example green hydrogen. Step three focuses on the renewal of the raw material and fuel system. In order for the Port of Rotterdam to remain an important global hub, investments in fast and reliable (digital) infrastructure are necessary. Investments in wet and dry infrastructure are important for the port to remain accessible to the largest vessels, to keep the hinterland accessible and to remain resilient in the face of climate change. To adapt to digitalisation and the knowledge economy, the Port of Rotterdam 2030 vision aims to create an efficient and innovative climate involving stakeholders from different backgrounds. The sustainability strategy of the Port of Rotterdam addresses the issues that are to be expected. The regular port vision of 2019 includes goals that start in 2019, that start within five years (2024) and start after 2030. The goals can deliver impact, for example providing residual heat, steam and CO_2 within five years and going on from there to additional electrification and green hydrogen after 2030. The goals are concrete to a certain extent: the port and industrial area must reduce CO_2 emissions by 49% by 2030 compared to 1990, be almost carbon neutral by 2050 (climate goals) and adhere to the legal air quality standard.

In 2022, the Port of Rotterdam produced the most recent progress report on the realization of the latest Port Vision goals published in 2019 (Port of Rotterdam, 2020). Despite the COVID-19 pandemic, the Port of Rotterdam intends to maintain the Port Vision goals. In 2020, the CO_2 emissions of Rotterdam were reduced by 12%, compared to an average of 8% for the Netherlands, with even more projects regarding energy transition planned to decrease CO_2 emissions by 12 million tonnes within the Port Area. The goal of keeping air quality within legal limits has been achieved. In 2021, the WHO has published stricter recommended air quality values, which are expected to be implemented in 2022. After the proposal, the effects on the Port of Rotterdam can be established (Port of Rotterdam, 2022b).

Table 75 - Multi-criteria analysis Port of Rotterdam

Topic	Coverage
Climate change	The Dutch Climate Agreement will become the deciding framework for the CO_2 reduction task of the port and industrial complex of Rotterdam. The Port of Rotterdam can play an important role in the energy and raw materials transition by facilitating alternative forms, such as offshore-wind, biomass and hydrogen. More effort will be put into expanding shore power supply. The Port of Rotterdam will invest heavily in green energy in the future. Examples are: residual heat, steam, shifting from CCS to CCU, (green) electrification, waste incineration, biofuels, synthetic fuels, hydrogen and bioLNG.
Energy transition	The port processes large quantities of biomass and it helps facilitate offshore wind in the North Sea. In 2030, the port and industrial area of Rotterdam will be the hub of the most climate-friendly transport fuels in the world. Some activities will remain non-circular. For these kind of activities, a limited greenhouse gas budget will be created that will eventually be carbon neutral. Circular initiatives will need to be accelerated, along with the necessary adjustments in the legal framework to give these initiatives space.
Digitalisation	Digital innovation increases value and creates new business models that will lead to prosperity and progress. Digitalisation of many port functions, from ship guidance to risk management, will create new working methods and new connections with parties within and

Topic	Coverage
	surrounding the port by 2030. Automation of container handling will be further developed. The emphasis will increasingly be on optimal collaboration and data exchange within the logistics sector. The goals do not become more specific, apart from the need for digital infrastructure to grow along with digital developments.
Economic trends and geopolitical shift	The economic centre of gravity shifts more towards Asia (China). Trade barriers between, for example, US and China, and Brexit will have an inhibitory effect on economic growth and thus on throughput volumes. The Port of Rotterdam can play an important role in the raw material transition, because it is an important link between regions of origin of raw materials and production locations. The port needs to keep expanding its infrastructure to remain future-proof (hydrogen, electricity, more competition) and remain an important hub.

Antwerp

In 2019, the Port of Antwerp produced a sustainability report on previously attained highlights in sustainability, strategic priorities and sustainability targets (Port of Antwerp, 2019). Sustainable growth is a target through diversifying activities, retaining added value and preserving employment. The Port of Antwerp works proactively to keep mobility smooth and the port accessible and sustainable, for which a modal shift from road transport to inland navigation and rail is essential. Through investments in selection, training and support of employees, the port must remain safe and attractive. Innovation and transition with regard to a low-carbon and circular economy, together with digitization, can make the supply chain more efficient and high-performance. Closing the raw material cycles and becoming more circular helps develop interest and a market share as a chemical-industrial cluster. To reduce its ecological footprint, the Port of Antwerp is committed to reducing air emissions, capturing and recycling CO_2, selectively collecting (plastic) waste, conserving fauna and flora through species protection programmes, increasing renewable energy production capacity and making transport greener. This is necessary to achieve its target of being climate neutral by 2050 (Port of Antwerp Bruges, 2022b). Hydrogen plays a major role in its ambitions to become Europe's green-energy hub. Hydrogen and hydrogen carriers will be imported, stored and converted into building blocks for the chemical sector.

Many of the (renewable) energy consumption, air and water quality goals for 2017 and/or 2018 have been reached. Few clear goals have been set out in the document. The goals continue to be that emissions need to drop, renewable energy and water/air quality need to rise and remain within the legal framework, but the goals or future steps are not specified further.

Table 76 - multi criteria analysis sustainability strategy Port of Antwerp

Topic	Coverage
Climate change	To reduce air emissions and pollutants, improvements in the shipping and industry areas are encouraged. Think of emission-reducing technologies for ships, reduction of port charges for green ships, shore power supply. The Port of Antwerp keeps track of air emissions quite extensively, and decreases over time are visible. There are no clear targets, except for decreasing the emissions and improving air quality.
Energy transition	Due to the large integrated fuel and chemical cluster, the energy intensity and GHG emissions are relatively high. Over the years, much has been invested in renewable energy, especially wind, solar and biomass. LNG has arrived as a clean alternative fuel, enabling the first steps towards hydrogen, methanol and electrical energy. The Antwerp Port Authority has concluded cooperation agreements with companies in order to encourage CCU

Topic	Coverage
	incentives. There are many opportunities to develop a circular economy in the port area. A roadmap has been created to develop this sector even more in the coming years.
Digitalisation	Digitisation and data sharing makes the port's supply chain increasingly high-performance, more efficient and safer. In previous years, much has been realised to make the port into a digital and innovative cluster, but these investments need to continue to remain up to date. Examples include digital cameras and sensors that help ships dock correctly, a digital network that spans the entire port area and various communities that lead to transparent and secure data exchange and digitization of logistical processes.
Economic trends and geopolitical shift	Not much is mentioned apart from the Port of Antwerp retaining its global perspective as a world port by remaining resilient. Its central location in relation to European consumption and production centre, its high productivity and premium quality of storage, transhipment, distribution and transport companies remain key assets.

Barcelona

The Port of Barcelona released a strategic plan in 2021 (Port De Barcelona, 2021b) containing a short-term and a long-term outlook. The strategy considers three themes: environmental, social and economic development. In the short term, the port aims to grow its foreign trade and workforce in order to promote social and economic sustainability. Environmental availability focusses on the introduction of an onshore power supply. Initially, this will be focused on container, cruise and ro-ro vessels. Especially in 2040, more electric mobility and alternative fuels will become very important.

In the longer term, other issues become important. These includes developing a new energy model by switching to clean alternative fuels, the production and management of renewable energy and reducing pollution. In the coming years, new plans will be developed for these issues. A second key point is to improve the environmental impact of hinterland transport. Historically, medium and long distance transport volumes have shifted from road to rail, but short distance transport is still often by truck. The port would like to shift these transport flows to rail as well. This will be done by developing a new rail terminal.

Table 77 - multi-criteria analysis sustainability strategy Port of Barcelona

Topic	Coverage
Climate change	The strategy describes climate change as a major short-term and long-term trend. The port has several targets. By 2030, the Port plans a 50% reduction in greenhouse gasses and by 2040 it hopes to be energy self-sufficient. By 2025, 50% of the container and ro-ro berths will be electrified.
Energy transition	The Port of Barcelona does not house a large industrial or energy production complex. As a result, energy transition is more focused on the user side. This means the introduction of onshore power and the provision of alternative fuels. Pilot projects are foreseen for the years up to 2025. Targets have also been set for new warehouses to become self-sufficient. The port has set a target to become a key player for the production and transhipment of green hydrogen in 2040.
Digitalisation	Digitalisation has accelerated at the Port of Barcelona due to the COVID-19 pandemic. It is mentioned as high short-term and long-term priority. Areas of interest include digitalizing forms and autonomous transportation. In 2040, the port wants to set up autonomous rail connections between different parts of the port.
Economic trends and geopolitical shift	The port is aware of the uncertainty of future trends and the possible decline of Europe as economic power. A short term target is to establish a close relationship with an additional

Topic	Coverage
	global Asian operator. The 2040 strategic plan distinguishes four possible future directions depending on global trends.

Bremen ports

The Port of Bremen has a sustainability report which includes a section on market presence and port development. Future projects are discussed under the heading ‘Future concept for the ports of Bremen in 2035’. Topics discussed include cooperative port activities, digitization, climate neutrality, energy transition and adaption to climate change.
The report is, however, not publicly available and for this reason no conclusions could be drawn.

Hamburg

The Port of Hamburg does not have a recent report on sustainable strategy. The latest report, from 2012, is no longer up to date.

Le Havre

The port authority of Le Havre mentions some areas in which investments will be made in the coming years. These include:
- offering clean energy solutions to ships and barges (through sea cruise terminal electrification in Le Havre and Rouen);
- deploying a fleet of electric vehicles;
- renovating heating in the Port of Rouen's main office;
- developing multimodality by encouraging modal transfer to river and rail;
- however there is no dedicated sustainable strategy report.

London

The Port of London Authority is part of a shared vision for the Thames in 2050. The vision is shared with various partners that use the river, including the City of London, ministerial departments and environmental agencies. The vision is built around three building blocks. First, the river will remain an important trading hub while producing net zero emissions. Secondly, the Thames will be accessible as a destination to live, visit and enjoy. This includes tourism and sports. The third is to have a clean river free of waste and pollution that can support good biodiversity.

In order to reach these goals five pillars of action have been constructed. These are:
1. Safety.
2. Transformation to net zero emissions.
3. Robust systems, infrastructure and habitats.
4. Technological change.
5. Access and inclusion to make the river accessible to all.

Concrete actions for each pillar are developed and monitored continuously.

Table 78 - multi criteria analysis sustainability strategy London

Topic	Coverage
Climate change	One pillar of changes is a shift to net zero. This involves replacing the use of fossil fuels with alternative fuels such as hydrogen. Carbon capture and storage is also being investigated by a waste processing plant. However, further actions or more concrete targets are not provided.
Energy transition	In the strategy, the port authority refers to the importance of a shift to alternative fuels. However, concrete long-term measures are not specified. Short-term action includes an onshore power point.
Digitalisation	The port is setting up a new port control centre with new port control technology.
Economic trends and geopolitical shift	The port is dredging the river in order to enhance port accessibility. The port anticipates growth in specific markets.

Los Angeles

The Port of Los Angeles has a 2018 short-term strategic plan that includes four objectives:
1. World-Class Infrastructure that Promotes Growth.
2. A Secure, Efficient and Environmentally Sustainable Supply Chain.
3. Improved Financial Performance of Port Assets.
4. Strong Relationships with Stakeholders.

Within this strategy, several initiatives are promoted that address several sustainable topics.
Short-term sustainability developments are expanding the electricity infrastructure for future needs and the further improvement of air quality. The port is developing a long-term plan addressing developments up to 2050 (City of Los Angeles Harbor Department & Port of Los Angeles, 2018).

Long Beach

The Port of Long Beach has a short-term strategic plan (Port of Long Beach, 2019). The strategic goals include:
- strengthen the port's competitive position through secure and efficient movement of cargo while providing outstanding customer service;
- maintain financial strength and security of assets;
- develop and maintain state-of-the-art infrastructure that enhances productivity and efficiency in goods movement;
- improve the environment through sustainable practices and the reduction of environmental impacts from port operations and development;
- broaden community access to port-related opportunities and economic benefits;
- attract, develop and retain a diverse, high-performing workforce.

The sustainable objectives include implementing a clean air programme and facilitating the transition to zero-emission port infrastructure. Ensuring the availability of reliable, resilient, cost-effective and sustainable energy. However, no clear targets are provided and no long-term strategy report is available. For this reason, no multi-criteria analysis was performed.

Vancouver

The Port of Vancouver has developed a scenario report for the year 2050. This was developed in 2010 and last updated in 2015. More than 100 stakeholders contributed to the vision of the future of the port. Key drivers of change include demographics, energy transition, gateway competitiveness and geopolitical stability.
The report discusses four different scenarios the port could find itself in, depending on global circumstances. One of these scenario is called the great transition, where the port operates in a post-carbon model. The report does not delve into the measures the port should take in relation to the scenarios.

12.3 Conclusions

When we look at the sustainable strategy of ports, we see differences in the extent towards ports have reports. Some ports have no information about sustainable strategy on their website. Other ports only present very limited information about their sustainable strategy or only for the short term. In these situations, the results could not be properly analysed. The same applies to reports which are drafted in ‘marketing terms’ and do not include concrete measures. We have looked at more detail at the sustainable strategy for four topics, namely climate change, energy transition, digitalisation and economic and geopolitical shifts. Among the ports that have a report of significant quality, we see the following developments:

- Climate change measures in the short term include shore power provision and carbon capture storage. Long-term developments are a shift to renewable energy sources.
- For the energy transition, ports are moving towards alternative and, in the future, renewable fuels. Many ports are involved in wind farming projects, on land as well as on sea. Transhipment of hydrogen is a target for many ports to replace fossil fuels. Long-term developments include a shift towards a circular economy and the change of energy carriers in industry.
- Digitalisation is another topic often mentioned in the reports. Some developments include the integration of data chains to better monitor the locations of goods and vessels. Also, port systems are becoming more integrated. Automation of container transport is also mentioned.
- Economic trends and geopolitical shift are discussed in several reports. Many ports acknowledge growing vessel sizes and the growing economies in East Asia. Some ports are therefore looking to partner with Asian companies. Several ports report that economies are becoming more protective. This hinders trade, but also offers opportunities. For example, for increased recycling or more local energy production. Which is relevant for hydrogen production for example.

13 Conclusions

Goal of the benchmark – progress and frontrunners

The benchmark serves two purposes. Firstly, to identify the sustainability progress of individual ports. Secondly, to identify frontrunners and best practices that can boost the sustainable development of seaports in general. We have analysed the sustainability of ports by various topics.

GHG emissions

Port emissions are mainly due to industrial facilities, power generation and transport. Results show that until 2020 there have been little or no improvements in absolute GHG emissions in recent years. The only exception is electricity generation, where the closure of several power plants has led to GHG reductions at a number of ports. while GHG emissions remained stable. Efficiency has however improved in several ports and individual industrial facilities as output increased. Early insights show that in 2021 and 2022 emissions have reduced due to production cuts as a result of high energy prices due to the war in Ukraine. These reductions are however not a consequence of a change in energy source as at this stage these port operations still depend on fossil fuels. Reducing GHG emissions in ports will require a change in energy carrier for industrial complexes and shipping. These transitions are still in their early stages, as observed elsewhere. For International ports we see that several ports do not have an overview of the emissions of greenhouse gases. Due to limits in data availability we have not made analysis of emissions relative to added value.

Air pollutant emissions

The air quality in ports has improved in recent decades in both Dutch and international ports. Concentrations of the main combustion pollutants NO_x, $PM_{2.5}$, SO_2 have reduced. This is not necessarily a consequence of port activities, as our analysis shows that emissions of nitrogen oxides have not decreased in Dutch ports in recent years. This is mainly due to increases in emissions from mobility and transportation. Relative to added value some ports show improvements whereas other do not. For particulate matter, a reduction has been observed in all ports for recent years. Other substances, such as lead, are mainly emitted by a small selection of industrial facilities in ports. In general, these emissions are declining, although the results are subject to large fluctuations from year to year. In international ports, there is more focus on monitoring concentrations relative to emissions. Improvements are visible for international ports as well.

Mitigation measures

Mitigation measures help reduce GHG emissions and air pollutants. We have looked at solutions related to industrial complexes, such as the use of biomass and residual heat, and transport-related solutions. Several solutions are taken by the ports that house an industrial complex. However, the emission reductions are limited compared to the GHG emitted. Carbon capture and storage is expected to deliver greater emission reductions and is currently being seriously explored by multiple ports. The same applies to shore power for maritime vessels. Due to impending European regulations, many ports are investing in shore power. This solution is already common for container and cruise vessels in North American ports. Other transport solutions, such as environmental zones for shipping and a successful slow sailing programme, are being implemented by the ports of Los Angeles and Long Beach.

Renewable energy quality

Ports are major users and producers of energy. This applies to the production of electricity in power plants as well as to fuels in refineries. In recent years, there have been many initiatives in renewable energy production. Wind power is still the main source of renewable electricity, although solar power has been steadily increasing in recent years. Biofuel production is increasing in Dutch ports, which seems to be related to European legislation. However, reporting of renewable energy production is often limited, making it difficult to draw definitive conclusions on the quantities produced in ports.

Water quality

In many European ports, water quality is unsatisfactory by European standards, although improvements are visible. The ports, which are mainly situated at the mouth of a river, are not the sole reason for the unsatisfactory water quality. Often the water quality was unsatisfactory even before the water entered the port. Emissions of substances to water in port areas are decreasing slightly over time. Of these emissions, a significant part is emitted by urban waste water centres situated in port areas. These waste water centres are mainly fed by sources outside the ports.

Waste management

Shipping waste is an important source of pollution in oceans. Waste ranges from oily substances to the so-called ‘plastic soup’ of household waste. The ports studied seem to be able to process the main types of maritime waste. However, further measures could reduce the illegal discharge of waste. If the cost of discharging waste is significant, such illegal discharges can be a financial incentive for vessel owners. The Netherlands has a system where vessels pay a fee regardless of the amount of waste discharged. When these vessels actually discharge waste, they receive a discount on the waste fees. This acts as an incentive to discharge waste. This system is the basis for a new system introduced in the European Union, which shows how good examples can be taken up by others.

Modal split

Hinterland transport options are to some extent determined by the location and characteristics of the port. Ports are still able to influence transport decisions given the background of the port. For example, investing in railway infrastructure can increase the proportion of train transport. Such measures lead to results that are mainly visible in the long term. Of the ports we studied, we observe that the ports of Bremen, Hamburg and Los Angeles improve their modal share in the long term.

Community relations

Ports take various measures to improve community relations. The efforts depend on the size of the port and its proximity to urban areas. As characteristics of ports differ, so do the focus points of the various ports. In general, there are many good examples of good community relations among the selected ports.

Sustainable strategy

Some ports have no sustainable strategy information on their website. Other ports present only very limited information about their sustainable strategy or only for the short term. In these situations, no proper analysis on the results could be performed. With regard to climate change, we found that short-term measures include shore power provision and carbon capture storage. Long-term developments include a shift towards renewable energy sources. Many ports are involved in wind farming projects on land as well as on sea. Transhipment of hydrogen is a goal for many ports in order to replace fossil fuels. Long-term developments include a shift towards a circular economy and the change of energy carriers in industry. Many ports mention that Asian economies are growing and protectionism is increasing.

Recommendations

In this second edition of the benchmark, the scope of the report has been expanded as more foreign port topics are included. Data availability is still one of the main limiting factors. Monitoring of sustainability criteria in many ports is often limited or related to official sources, as in the case of emissions and water quality. The collected data is to a large extent dependent on national or international initiatives like Emissieregistratie in the Netherlands and E-PRTR in the EU. Data collected by ports is not streamlined and therefore heterogeneous. This makes it at times difficult to draw conclusions. Unfortunately, this second edition has not brought major improvements in the amount of data provided by port authorities and other relevant stakeholders. Gathering the data is still an intensive process with at times unsatisfactory responses.

Nevertheless, the process has resulted in an overview that provides interesting results compared to the previous edition:

- Shore power and alternative fuels are more prominent compared to the previous edition. There seems to be a direct link to European policies, which highlights that policies can have an accelerating function;
- The large scale transition towards renewable energy is still in its early stages. This applies to both shipping and industrial processes;
- By including results from previous editions, some developments have become clearer:
  - modal split improvements are visible as the time period increases;
  - renewable energy improvements are more visible.

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A Data sources

A.1 Dutch ports

Port of Amsterdam

	2018	2019	2020	2021	Source
Wind capacity (MW)	64	75		77	(Noord-Hollandse Energie Regio, 2020) (Port of Amsterdam, 2019)
Solar pv capacity (MW)	7	9		20	(Van Gastel, 2019) (Port of Amsterdam, 2020a)
Biomass power station capacity (MW)			40	40	(RVO, 2023)
Biogas production capacity (nm^3/h)				2,000	(Orgaworld, 2022) (Og Clean Fuels, n.d.)
Biofuel production capacity (ton)	100,000	100,000	100,000	100,000	(Port of Amsterdam, 2022) (Argent Energy, lopend)
Share storage capacity biofuels			5,40%	5,70%	(Gemeente Amsterdam, 2022)
Biomass total production (Mton CO_2e)				0.096	(Aeb Amsterdam, n.d.)
Biomass total				For 17,000 households	(Intal, 2020)
Biomass total production (TJ warmth)				1,656	(Aeb Holding N.V., 2021)
Residual heat used (GWh)			300		(Nzkg Noordzeekanaalgebied, 2022)
Residual heat emissions saved (Kton CO_2e)			37,105	55,375	(Vattenfall, 2022a) (Orgaworld, n.d.) (Vattenfall, n.d.)
Onshore Power Supply (OPS) for IWT number of installations				53	Contact with port authority

Groningen Seaports

	2018	2019	2020	2021	Source
Wind capacity (MW)	426	414	413.7	n/a	(Groningen Seaports, 2018, 2019, 2020)
Solar pv capacity (MW)	42	43	53.6	n/a	(Groningen Seaports, 2018, 2019, 2020)
CO_2 capture and usage (CCU) (Mton CO_2e)			Photanol uses transformed cyanobacteria to make highly-efficient mini-factories that absorb more CO_2 and produce oxygen		(Photanol, n.d.)

	2018	2019	2020	2021	Source
Waste incineration energy production (TWh)				4.1	(EEW, 2022b) (Noord-Nederland, 2021)
Residual heat (TJ per year)	3.200	3.200	3.200	3.200	(Rijksdienst Voor Ondernemend Nederland, 2015)
Biofuel production (PJ)	50	50	49.9		(Groningen Seaports, 2018, 2019, 2020) (Provincie Groningen, 2017)
Biofuel production capacity (ton)				0.45	(Sn-Gave, n.d.-b) (Sn-Gave, n.d.-a)
Biomass production electricity and heat (MW)	234.8	234.8	234.8	234.8	(Eneco, n.d.) (Groningen Seaports, n.d.-a)
Onshore Power Supply (OPS) for IWT number of installations	229	229	229	229	Contact with port authority
Onshore power supply (mWh per year)	1,114	1,113	1.396	1.495	(Groningen Seaports, 2021) (Groningen Seaports, 2019)

Port of Moerdijk

	2018	2019	2020	2021	Source
Wind capacity (MW)				25	(Vattenfall, 2022b)
Solar pv capacity (MW)		27	27	35	(Van Erne, 2020)
Biomass power station capacity (MW)	32	32	32	32	(Pzem, 2021)
Sustainably produced electricity (mWh)	610,000	1,039,977	1,023,138		(Moerdijk, 2020) (Port of Moerdijk, 2021)
% of total energy production from renewable sources		61.5			(Port of Moerdijk, 2020)
Residual heat (mWh per year)	1,687	2,183	1,875		(Havenschap Moerdijk, n.d.)
Steam (MW)	120	120	120	120	(Attero, 2018, 2022)
Onshore Power Supply (OPS) for IWT number of installations	10	10	10	10	Contact with port authority and walstroom.eu (Ease2pay Walstroom, 2023)

North Sea Port

	2018	2019	2020	2021	2022	Source
Wind capacity (MW)				280	300	(North Sea Port, 2022b) & communication with Port Authority
Solar pv capacity (MW)	65			110		(North Sea Port, 2022b)
Solar pv capacity (kWh)					25.4 mil	(Kieszon, 2022)
Offshore wind capacity (GW)				1.5		(North Sea Port, 2020)

	2018	2019	2020	2021	2022	Source
Biomass power station capacity (MW)					20	(Bio Energy Base, 2023)
CO_2 capture and usage (CCU) (Mton CO_2e)				0.1	0.055	(North Sea Port, 2022c, Alcobiofuel, 2022) (Warmco2, n.d.)
CO_2 capture and usage (CCU) (Mton CO_2e)					0.125	(North Sea Port, 2022a)
CO_2 emissions in Belgian part of North Sea Port		12,800 Kton	11,111 Kton			(North Sea Port & Econopolis, 2022) (Aeb Holding N.V., 2021)
Biogas production (m^3 or PJ)					40 million m^3/1.41 PJ	(Sfp Group, n.d.-b)
Biomass total production (tonnes output)					250,000 tonnes	(Sfp Group, n.d.-a)
Biofuel production (Mton CO_2 saved)					0.285	(Bee, 2022)
Biofuel production (tonne or PJ)					115,000 tonne biodiesel, 0.628 PJ	(Pzc, 2022)
Biofuel production (tonne)					120,000 tonne bio-ethanol	(Eiffage, n.d.)
Hydrogen (Kton)					580	(North Sea Port, n.d.)
Onshore Power Supply (OPS) for IWT number of installations	68	80		82		Contact with port authority, previous study, (Navingo Career, 2013)

Port of Rotterdam

	2018	2019	2020	2021	2022	Source
Wind capacity (MW)	193.6	183.5	195		311	(Port of Rotterdam, 2021b)
Solar pv capacity (MW)	7	11	11	18	18	(Port of Rotterdam, 2022b)
Biomass power station capacity (MW)	20	20	20	20		(Mourik Bouw, 2009)
Biofuel production capacity (Mton)[19]	2.4			1.56 (incomplete)		(Gemeente Rotterdam, 2019) (Sn-Gave, 2022b, 2022a)

[19] This does not represent a reduction in biomass. In 2019, an overview of biofuel production was available which gives a complete picture. In 2021, a project regarding biofuels is included which does not represent the complete scope of all biofuel produced in the port area.

% of total energy production from renewable sources	4.90					(Port of Rotterdam, 2022b)
Transhipment of biomass (mln. tonne)	0.5	0.9	1.8	2.2		(Port of Rotterdam, 2022b)
CO_2 capture and usage (CCU) (Mton CO_{2e} saved)	0.25			0.6		(Ocap, 2022) (Hortipoint, 2021) (Ocap, 2022)
Biomass total (Mton CO_{2e})		1.5	2.1	1.9		(DCMR Milieudienst Rijnmond, 2021, 2022, 2020)
Residual heat estimated on potential houses (mWh per year)	1,217,992	1,217,879				(Port of Rotterdam, 2022b)
Residual heat (Residual heat potential for houses)	129,000	128,988				(Port of Rotterdam, 2022b)
Onshore Power Supply (OPS) for IWT number of installations			480			(Schone Lucht Akkoord, 2021)
Onshore power supply (mWh per year)	1,217	1,206	855	1,147		(Port of Rotterdam, 2022c)

A.2 International ports

In this chapter we provide an overview of the sustainable data collected for Dutch and international ports. We have also used data collected in the previous edition of the benchmark (CE Delft, 2020). This information is not included in the figures below but can be found in the previous edition of the benchmark.

Port of Antwerp

	2010	2015	2018	2019	2020	2021	Source
Size of port (land) square km						114.65	(Port of Antwerp Bruges, 2022a)
Total throughput						240	(Port of Antwerp Bruges, 2022a)
GHG emissions in port areas (Mton CO_2)				16	15.9	16.2	(Tom Cochez, 2021) (Port of Antwerp Bruges, n.d.-b) (Our Sustainable Port, n.d.)
Nitrogen Oxides emissions (NO_x) ktonnes	23.7	22		19.3	18		(Vlaamse Milieumaatschappij, 2023)
Particulate matter emissions ($PM_{2.5}$)	0.7605	0.653		0.667	0.681		(Vlaamse Milieumaatschappij, 2023)

	2010	2015	2018	2019	2020	2021	Source
Particulate matter emissions (PM_{10})	1.15	1.03		1.07	1.11		(Vlaamse Milieumaatschappij, 2023)
Sulphur Oxides emissions (SO_2)	22	14	12	11	8	8	(Vlaamse Milieumaatschappij, 2023)
Nitrogen Dioxide (NO_2) concentration ($\mu g/m^3$)	38	32	31	29	25	26	(Vlaamse Milieumaatschappij, 2021)
Nitrogen Oxides (NOx) concentration ($\mu g/m^3$)	22	14	12	11	8	8	(Vlaamse Milieumaatschappij, 2021)
Particulate Matter ($PM_{2.5}$) concentration ($\mu g/m^3$)	26	13	n/a	13	12	12	(Vlaamse Milieumaatschappij, 2021)
Particulate Matter (PM_{10}) concentration ($\mu g/m^3$)	28.9	22.9	n/a	22.9	22.07	22	(Vlaamse Milieumaatschappij, 2021)
Sulphur Oxides (SO_2) concentration ($\mu g/m^3$)	6	4	5	4	4	4	(Vlaamse Milieumaatschappij, 2021)
Wind capacity (MW)			150	190	190	190	(Port of Antwerp Bruges, n.d.-a)
Solar pv capacity (MW)			70	70	70	70	(Port of Antwerp Bruges, n.d.-a) (Port of Antwerp, 2019) (Port of Antwerp Bruges, 2021)
CO_2 capture and usage (CCU) (Mton CO_{2e} saved)			n.a.	n.a.	n.a.	n.a.	(Port of Antwerp, 2019)
Residual heat (Mton CO_2 saved)						0.1	(Port of Antwerp Bruges, n.d.-a)
Percentage of vessels receiving discount		%		11%	9%		(Vlaamse Milieumaatschappij, 2021)
Onshore Power Supply (OPS) for IWT number of installations						25	(Port of Antwerp Bruges, n.d.-b)
Share pipelines				n/a	15		(Port of Antwerp Bruges, 2022a)
Share trucks				58	34		(Port of Antwerp Bruges, 2022a)
Share river barges				35	44		(Port of Antwerp Bruges, 2022a)
Share trains				7	7		(Port of Antwerp Bruges, 2022a)

Port of Barcelona

	2007	2018	2019	2020	2021	Source
Size of port (land) square km			11.1	11.1	11.1	(Port De Barcelona, n.d.)
Total throughput				43.4	47.4	(Port De Barcelona, 2022a)
GHG emissions (ktonne)				315		(Port De Barcelona, 2021a)
Nitrogen oxide emissions (ktonne)				6.2		(Port De Barcelona, 2021a)
Nitrogen Oxides (NO_x) concentration ($\mu g/m^3$)		40.9	41.2	32.4		(Port De Barcelona, 2021a)
Particulate Matter (PM_{10}) concentration ($\mu g/m^3$)		31.9	34.3	30.8		(Port De Barcelona, 2021a)
Sulphur Oxides (SO_2) concentration ($\mu g/m^3$)		2.1	1.8	1		(Port De Barcelona, 2021a)
Solar pv capacity (MW)		n.a.	n.a.	n.a.	7	(Port De Barcelona, 2022b)
Biomass total (Mton CO_{2e})		n.a.	n.a.	n.a.	n.a.	(Alt Fuels, 2022)
Number of bunkerings LNG			1,950	219		(Port De Barcelona, 2021a)
Number of bunkerings LNG (m^3 per year)			37,545	39,149		(Port De Barcelona, 2021a)
share trucks in hinterland transport	97%		87%	83.90%		(Railfreight.Com, 2018) (Port Technology International, 2021)
share trains in hinterland transport	3%		13%	16.10%		(European Commission, 2011)

Bremen ports

	2018	2019	2020	2021	Source
Size of port (land) square km				46	(World Port Source, n.d.)
Total throughput		69.4	66.5	69.7	(Bremen Ports, 2022a)
Bremerhaven Nitrogen Dioxide (NO_2) concentration ($\mu g/m^3$)		20	18	19	Contact with port authority
Bremerhaven Particulate Matter ($PM_{2.5}$) concentration ($\mu g/m^3$)		11	9	9	Contact with port authority
Bremerhaven Particulate Matter (PM_{10}) concentration ($\mu g/m^3$)		18	15	15	Contact with port authority
Bremerhaven Sulphur Oxides (SO_2) concentration ($\mu g/m^3$)		1	1	1	Contact with port authority

Bremen Nitrogen Dioxide (NO_2) concentration (µg/m^3)		13	11	12	Contact with port authority
Bremen Particulate Matter ($PM_{2.5}$) concentration (µg/m^3)		11	9	10	Contact with port authority
Bremen Particulate Matter (PM_{10}) concentration (µg/m^3)		19	17	17	Contact with port authority
Bremen Sulphur Oxides (SO_2) concentration (µg/m^3)		2	1	1	Contact with port authority
Bremerhaven Percentage of vessels receiving discount		49	56	39	(Bremen Ports, 2022b)
Bremen Percentage of vessels receiving discount		21	27	14	(Bremen Ports, 2022b)
Number of shore power connections IWT	21	21	20	20	(Bremen Ports, 2022b)
share trucks hinterland transport		49%	49%	48%	(Statista, 2022)
share river barges hinterland transport		3%	3%	4%	(Statista, 2022)
share trains hinterland transport		48%	48%	48%	(Statista, 2022)

Port of Hamburg

		2018	2019	2020	2021	Source
Size of port: Land					43	(Port of Hamburg, n.d.)
Size of port: total					74	(Port of Hamburg, n.d.)
Size of port value added			9,800			(Isl, 2021)
Total throughput					128.7	(Port of Hamburg, 2023b)
Bremerhaven Nitrogen Dioxide (NO_2) concentration (µg/m^3)			31.0	27.0	27.0	(Hamburg, 2022)
Bremerhaven Particulate Matter (PM_{10}) concentration (µg/m^3)			18.00	18.00	18.00	(Hamburg, 2022)
Bremerhaven Sulphur Oxides (SO_2) concentration (µg/m^3)			4			(Hamburg, 2022)
Residual heat (Mton CO_2)			0.032	0.032	0.032	(Aurubis, 2021) (Energiewende Direkt, 2017)
Onshore Power Supply (OPS) number of installations maritime vessels			1	1	1	(Hamburg Port Authority, n.d.)

share trucks hinterland container transport	46%				38%	(Port of Hamburg, 2023a) (Lupi et al., 2021)
share river barges hinterland container transport	12%				9%	(Port of Hamburg, 2023a) (Lupi et al., 2021)
share trains hinterland container transport	42%				54%	(Port of Hamburg, 2023a) (Lupi et al., 2021)

Port of Le Havre

	2018	2019	2020	2021	2022	Source
Size of port land square km					100	(Haropa Port, 2022b)
Size of port total square km					160	(Haropa Port, 2022b)
Total throughput				93		(Haropa Port, 2021) (Haropa Port, 2022b)
Onshore Power Supply (OPS) number of installations				1		(Cruisemapper, 2020)
share trucks hinterland container transport	82%	83%				(Haropa Port, 2021) (Haropa Port, 2022a)
share river barges hinterland container transport	4.40%	3.80%				(Haropa Port, 2021) (Haropa Port, 2022a)
share trains hinterland container transport	9.50%	9.20%				(Haropa Port, 2021) (Haropa Port, 2022a)
share short sea hinterland container transport	3.90%	4.10%				(Haropa Port, 2021) (Haropa Port, 2022a)

Port of London

	2018	2019	2020	2021	2022	Source
Size of port total						Own analysis based on port map
Size of port: Value added million euro						(Port of London Authority, 2020)
Total throughput		54	47.4	51.8		(Eurostat, 2022)
Percentage of vessels receiving discount %		211 vessels/ 1184 visits				(Port of London Authority, 2022)
Wind		2.3	2.3	2.3		(British Ports Association, 2020)
Biofuels production (PJ)		40	40	40		(Aalborg Energie Technik a/S, n.d.)

Port of Long Beach

	2018	2019	2020	2021	Source
Size of port: land square km				14	(Port of Long Beach, n.d.-a)
Total throughput (Mton)				90	(Port of Long Beach, n.d.-a)
GHG emissions in port area (ktonne)		806	878	1,189	(Port of Long Beach, 2022a)
Nitrogen Oxides emissions (NOx) ktonnes		6.61	5.77	7.76	(Port of Long Beach, 2022a)
Particulate matter emissions ($PM_{2.5}$) ktonnes		0.13	0.10	0.16	(Port of Long Beach, 2022a)
Particulate matter emissions (PM_{10}) ktonnes		0.14	0.11	0.17	(Port of Long Beach, 2022a)
Sulphur Oxides emissions (SO_2) ktonnes		0.21	0.20	0.28	(Port of Long Beach, 2022a)
Nitrogen Dioxide (NO_2) concentration ppm	0.0175	0.0165	0.0155	0.0175	(Clean Air Action Plan, n.d.)
Particulate Matter ($PM_{2.5}$) concentration ppm	7.3-9.5	9.8-12.5	9.5-11.3	7.3-9.5	(Clean Air Action Plan, n.d.)
Particulate Matter (PM_{10}) concentration ppm	21-37.4	26.4-38.1	22.9-32.1	21-37.4	(Clean Air Action Plan, n.d.)
Sulphur Oxides (SO_2) concentration ppm	0.003	0.0012	0.00125	0.003	(Clean Air Action Plan, n.d.)
Onshore Power Supply (OPS) usage		70%	80%	80%	(Port of Long Beach, n.d.-b)
Solar pv (MW)		0.9	0.9	0.9	(Edison Energy, n.d.) (A. Gupta, 2016) (Port of Long Beach, 2022b)

Port of Los Angeles

	2015	2019	2020	2021	Source
Size of port: land square km				30.375	(Port of Los Angeles, 2022b)
Total throughput (Mton)		207.3	183	222	(Port of Los Angeles, 2023)
GHG emissions in port area (ktonne)		879	899	1,253	(Port of Los Angeles, 2022c)
Nitrogen Oxides emissions (NOx) ktonnes		6.172	5.672	8.729	(Port of Los Angeles, 2021) (Port of Los Angeles, 2020) (Port of Los Angeles, 2022c)
Particulate matter emissions ($PM_{2.5}$) ktonnes		0.118	0.108	0.168	(Port of Los Angeles, 2021) (Port of Los Angeles, 2020) (Port of Los Angeles, 2022c)
Particulate matter emissions (PM_{10}) ktonnes		0.127	0.117	0.182	(Port of Los Angeles, 2021) (Port of Los Angeles, 2020) (Port of Los Angeles, 2022c)
Sulphur Oxides emissions (SO_2) ktonnes		0.109	0.104	0.255	(Port of Los Angeles, 2021)

	2015	2019	2020	2021	Source
					(Port of Los Angeles, 2020) (Port of Los Angeles, 2022c)
Nitrogen Dioxide (NO_2) concentration ppm	0.017	0.0115	0.013	0.013	(Clean Air Action Plan, n.d.)
Particulate Matter ($PM_{2.5}$) concentration ppm		5.2	7.5	5.35	(Clean Air Action Plan, n.d.)
Particulate Matter (PM_{10}) concentration ppm		22.25	24.9	27.7	(Clean Air Action Plan, n.d.)
Solar pv (MW)		13	13	13	(Port of Los Angeles, n.d.-b)
Share truck hinterland transport		65%			(Port of Los Angeles, n.d.-a)
Share rail hinterland transport		35%			(Port of Los Angeles, n.d.-a)

Port of Vancouver

	2015	2019	2020	2021	2022	Source
Size of port: land square km				15		(Port of Vancouver, n.d.)
Total throughput (Mton)			145	146		(Portnews, 2022)
GHG emissions in port area (ktonne)			1,190			(Port of Vancouver, n.d.) Minimize air emissions
Nitrogen Oxides emissions (NO_x) ktonnes	12.971		10.543			(Port of Vancouver, 2017)
Particulate matter emissions ($PM_{2.5}$) ktonnes	0.288		0.257			(Port of Vancouver, 2017)
Sulphur Oxides emissions (SO_2) ktonnes	0.265		0.28			(Port of Vancouver, 2017)
Nitrogen Dioxide (NO_2) concentration ppm		13.6	11.37	12.9	13.6	(Port of Vancouver, 2017)
Nitrogen oxides (NO_x) concentration ppb		29.7	22.7	24.8	29.7	(Port of Vancouver, 2017)
Particulate Matter ($PM_{2.5}$) concentration ppm		6.9	7.39	6.08	6.9	(Port of Vancouver, 2017)
Sulphur Oxides (SO_2) concentration ppb		0.28	0.26	0.29	0.28	(Port of Vancouver, 2017)
Maritime shore Power Supply (OPS) number of installations			4	4	4	(Port of Vancouver, n.d.) Minimize air emissions

	2015	2019	2020	2021	2022	Source
Onshore Power Supply (OPS) usage GHG emissions reduces (ton CO_2)		4,366	291	148	6,866	(Port of Vancouver, 2023)
Onshore Power Supply (OPS) number of unique vessels		700	8	n/a	n/a	(Port of Vancouver, 2023)

B Emissions in Dutch port areas by source

Emissieregistratie reports emissions for a range of different sources, including industry, energy production and transport. This Annex shows the results for Dutch ports specified by sector. Firstly, the results for GHG emissions are shown. Secondly, the results for air quality emissions are shown.

B.1 Emission of greenhouse gasses by source

Table 79 - CO_2 emissions Port of Amsterdam by source

Kton CO_2	2010	2015	2019	2020
Agriculture	11	0	0	0
Chemical industry	67	70	54	53
Construction	19	2	2	8
Consumers	572	11	10	5
Drinking water supply	0	-	-	-
Energy sector	1,850	4,195	3,209	861
Mobility and transport	515	285	386	392
Nature	-	-	-	-
Other industry	175	114	112	111
Refineries	0	0	42	41
Sewage treatment	19	25	38	36
Trade, services and government	341	78	54	50
Waste disposal	987	1,234	1,088	1,312
Total	**4,556**	**6,014**	**4,998**	**2,869**

Table 80 - CO_2 emissions Port of Groningen by source

Kton CO_2	2010	2015	2019	2020
Agriculture	14	2	3	3
Chemical industry	526	518	688	951
Construction	1	0	0	0
Consumers	39	7	7	6
Drinking water supply	-	-	-	-
Energy sector	6,499	9,426	10,870	7,456
Mobility and transport	45	34	35	31
Nature	-	-	-	-
Other industry	156	60	139	121
Refineries	0	3	5	5
Sewage treatment	1	1	1	1
Trade, services and government	13	13	11	11
Waste disposal	59	476	645	866
Total	**7,352**	**10,541**	**12,403**	**9,449**

Table 81 - CO_2 emissions Port of Moerdijk by source

Kton CO_2	2010	2015	2019	2020
Agriculture	19	1	1	1
Chemical industry	2,584	1,342	2,299	2,507
Construction	5	3	1	2
Consumers	37	2	2	2
Drinking water supply	-	-	-	-
Energy sector	1,009	986	1,153	892
Mobility and transport	166	96	95	88
Nature	-	-	-	-
Other industry	69	68	59	60
Refineries	0	0	0	0
Sewage treatment	-	-	-	-
Trade, services and government	15	6	6	5
Waste disposal	1,384	1,390	1,351	1,266
Total	**5,288**	**3,894**	**4,966**	**4,823**

Table 82 - CO_2 emissions Port of Rotterdam by source

Kton CO_2	2010	2015	2019	2020
Agriculture	484	21	24	23
Chemical industry	2,638	3,674	3,111	2,895
Construction	33	11	11	12
Consumers	995	185	179	101
Drinking water supply	1	0	0	0
Energy sector	11,085	14,676	11,069	9,989
Mobility and transport	2,271	1,514	1,549	1,792
Nature	-	-	-	-
Other industry	732	556	408	379
Refineries	8,600	9,631	9,835	9,226
Sewage treatment	32	39	39	42
Trade, services and government	617	403	880	766
Waste disposal	1,641	1,456	1,729	1,767
Total	**29,128**	**32,166**	**28,834**	**26,991**

Table 83 - CO_2 emissions North Sea Port (Dutch part) by source

Kton CO_2	2010	2015	2019	2020
Agriculture	7	3	3	2
Chemical industry	5,800	5,221	5,786	6,772
Construction	7	2	1	1
Consumers	153	26	25	25
Drinking water supply	-	-	-	-
Energy sector	5,747	4,060	1,725	1,799
Mobility and transport	366	237	269	281
Nature	-	-	-	-
Other industry	485	273	295	292
Refineries	1,394	1,543	1,589	1,167
Sewage treatment	6	8	8	8
Trade, services and government	51	25	24	23
Waste disposal	20	26	20	19
Total	**14,037**	**11,423**	**9,745**	**10,389**

Table 84 - CH_4 emissions Port of Amsterdam by source

Kton CH_4	2010	2015	2019	2020
Agriculture	-	0.2	0.2	0.2
Chemical industry	0.0	0.0	0.0	0.0
Construction	0.0	0.0	0.0	0.0
Consumers	0.6	0.4	0.4	0.4
Drinking water supply	0.0	0.0	0.0	0.0
Energy sector	0.5	0.4	0.3	0.3
Mobility and transport	0.1	0.1	0.1	0.1
Nature	0.1	0.1	0.1	0.1
Other industry	0.1	0.0	0.0	0.0
Refineries	-	-	0.0	0.0
Sewage treatment	0.4	0.5	0.6	0.5
Trade, services and government	0.1	0.1	0.1	0.1
Waste disposal	2.8	8.0	2.8	2.6
Total	**4.8**	**9.8**	**4.5**	**4.2**

Table 85 - CH4 emissions Groningen Seaports by source

Kton CH_4	2010	2015	2019	2020
Agriculture	-	0.4	0.4	0.4
Chemical industry	0.1	0.1	0.1	0.1
Construction	0.0	0.0	0.0	0.0
Consumers	0.0	0.0	0.0	0.0
Drinking water supply	-	-	-	-
Energy sector	0.6	0.4	0.4	0.3
Mobility and transport	0.0	0.0	0.0	0.0
Nature	0.1	0.1	0.1	0.1
Other industry	0.0	0.0	0.0	0.0
Refineries	-	-	-	-
Sewage treatment	0.0	0.0	0.0	0.0
Trade, services and government	0.0	0.0	0.0	0.0
Waste disposal	0.0	0.0	0.0	0.0
Total	**0.8**	**1.0**	**1.0**	**0.9**

Table 86 - CH4 emissions Port of Moerdijk by source

Kton CH_4	2010	2015	2019	2020
Agriculture	-	0.3	0.4	0.3
Chemical industry	0.1	0.1	0.1	0.1
Construction	0.0	0.0	0.0	0.0
Consumers	0.0	0.0	0.0	0.0
Drinking water supply	-	-	-	-
Energy sector	0.0	0.0	0.0	0.0
Mobility and transport	0.0	0.0	0.0	0.0
Nature	0.2	0.1	0.1	0.1
Other industry	0.0	0.0	0.0	0.0
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	0.0	0.0	0.0	0.0
Waste disposal	2.7	2.0	1.1	1.1
Total	**3.1**	**2.7**	**1.8**	**1.6**

Table 87 - CH_4 emissions Port of Rotterdam by source

Kton CH_4	2010	2015	2019	2020
Agriculture	-	3.6	4.2	3.8
Chemical industry	0.2	0.3	0.2	0.1
Construction	0.0	0.0	0.0	0.0
Consumers	0.9	0.6	0.6	0.5
Drinking water supply	0.1	0.1	0.1	0.1
Energy sector	1.1	1.5	1.3	1.1
Mobility and transport	0.2	0.2	0.2	0.2
Nature	0.3	0.2	0.2	0.2
Other industry	0.1	0.1	0.1	0.1
Refineries	2.1	0.5	0.5	0.5
Sewage treatment	0.3	0.4	0.5	0.5
Trade, services and government	0.1	0.1	0.1	0.1
Waste disposal	0.3	0.3	0.2	0.2
Total	**5.8**	**7.9**	**8.1**	**7.4**

Table 88 - CH_4 emissions North Sea Port by source

Kton CH_4	2010	2015	2019	2020
Agriculture	-	0.6	0.6	0.6
Chemical industry	0.5	0.4	0.2	0.4
Construction	0.0	0.0	0.0	0.0
Consumers	0.1	0.1	0.1	0.1
Drinking water supply	-	-	-	-
Energy sector	0.1	0.1	0.0	0.0
Mobility and transport	0.0	0.0	0.0	0.0
Nature	0.4	0.4	0.4	0.4
Other industry	0.0	0.0	0.2	0.2
Refineries	-	-	0.0	0.0
Sewage treatment	0.1	0.1	0.1	0.1
Trade, services and government	0.0	0.0	0.0	0.0
Waste disposal	4.6	5.3	4.7	4.4
Total	**6.0**	**7.0**	**6.4**	**6.2**

Table 89 - N_2O emissions Port of Amsterdam by source

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.03	0.03	0.02
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.01	0.01	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.03	0.07	0.06	0.03
Mobility and transport	0.02	0.03	0.03	0.03
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	-	-	0.00	0.00
Sewage treatment	0.01	0.01	0.01	0.01
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.04	0.04	0.03	0.04
Total	**0.12**	**0.19**	**0.18**	**0.16**

Table 90 - N_2O emissions Groningen Seaports by source

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.05	0.04	0.04
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.00	0.09	0.11	0.10
Mobility and transport	0.00	0.00	0.00	0.00
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.01	0.02	0.02
Total	**0.01**	**0.16**	**0.18**	**0.16**

Table 91 - N_2O emissions Port of Moerdijk by source

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.03	0.03	0.03
Chemical industry	0.02	0.02	0.01	0.01
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.02	0.02	0.03	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.13	0.11	0.09	0.09
Total	**0.17**	**0.19**	**0.17**	**0.14**

Table 92 - N_2O emissions Port of Rotterdam by source

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.05	0.06	0.06
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.01	0.02	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.10	0.14	0.07	0.05
Mobility and transport	0.07	0.08	0.08	0.09
Nature	0.01	0.01	0.01	0.01
Other industry	0.00	0.00	0.00	0.00
Refineries	0.05	0.06	0.37	0.20
Sewage treatment	0.01	0.01	0.01	0.01
Trade, services and government	0.01	0.00	0.00	0.00
Waste disposal	0.05	0.06	0.05	0.04
Total	**0.32**	**0.44**	**0.67**	**0.49**

Table 93 - N_2O emissions North Sea Port by source

Kton N_2O	2010	2015	2019	2020
Agriculture	-	0.09	0.09	0.09
Chemical industry	0.79	0.74	0.87	0.53
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.03	0.03	0.00	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	0.01	0.01	0.01	0.01
Other industry	0.00	0.00	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.01	0.01
Total	**0.85**	**0.88**	**1.00**	**0.65**

Table 94 - SF_6 emissions Port of Amsterdam by source

Ton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	-
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	-	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.31	0.29	0.27	0.27
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.31**	**0.29**	**0.27**	**0.27**

Table 95 - SF_6 emissions Groningen Seaports by source

Ton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	0.03
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	0.02	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.01	0.01	0.01	0.01
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.01**	**0.01**	**0.02**	**0.04**

Table 96 – SF_6 emissions Port of Moerdijk by source

Ton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	-
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	-	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.01	0.01	0.01	0.01
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.01**	**0.01**	**0.01**	**0.01**

Table 97 – SF_6 emissions Port of Rotterdam by source

Ton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	-
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	-	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.44	0.41	0.39	0.39
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.44**	**0.41**	**0.39**	**0.39**

Table 98 – SF_6 emissions North Sea Port by source

Ton SF_6	2010	2015	2019	2020
Agriculture	-	-	-	-
Chemical industry	-	-	-	-
Construction	-	-	-	-
Consumers	-	-	-	-
Drinking water supply	-	-	-	-
Energy sector	-	-	-	-
Mobility and transport	-	-	-	-
Nature	-	-	-	-
Other industry	0.04	0.03	0.03	0.03
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	-	-	-	-
Waste disposal	-	-	-	-
Total	**0.04**	**0.03**	**0.03**	**0.03**

Table 99 – CO_2-eq. Port of Amsterdam by source

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	11	0	0	0
Chemical industry	67	70	54	53
Construction	19	2	2	8
Consumers	572	11	10	5
Drinking water supply	0	0	0	0
Energy sector	1,850	4,195	3,209	861
Mobility and transport	515	285	386	392
Nature	0	0	0	0
Other industry	175	114	112	111
Refineries	0	0	42	41
Sewage treatment	19	25	38	36
Trade, services and government	341	78	54	50
Waste disposal	987	1,234	1,088	1,312
Total	**4,556**	**6,015**	**4,998**	**2,869**

Table 100 - CO_2-eq. Groningen Seaports by source

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	14	3	3	3
Chemical industry	526	518	688	951
Construction	1	0	0	0
Consumers	39	7	7	6
Drinking water supply	-	-	-	-
Energy sector	6,499	9,426	10,870	7,456
Mobility and transport	45	34	35	31
Nature	0	0	0	0
Other industry	156	60	139	121
Refineries	0	3	5	5
Sewage treatment	1	1	1	1
Trade, services and government	13	13	11	11
Waste disposal	59	476	645	866
Total	**7,352**	**10,541**	**12,404**	**9,449**

Table 101 - CO_2-eq. Port of Moerdijk by source

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	19	1	1	1
Chemical industry	2,584	1,342	2,299	2,507
Construction	5	3	1	2
Consumers	37	2	2	2
Drinking water supply	0	0	0	0
Energy sector	1,009	986	1,153	892
Mobility and transport	166	96	95	88
Nature	0	0	0	0
Other industry	69	68	59	60
Refineries	0	0	0	0
Sewage treatment	0	0	0	0
Trade, services and government	15	6	6	5
Waste disposal	1,384	1,390	1,351	1,266
Total	**5,288**	**3,894**	**4,966**	**4,823**

Table 102 - CO_2-eq. Port of Rotterdam by source

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	484	21	24	23
Chemical industry	2,638	3,674	3,111	2,895
Construction	33	11	11	12
Consumers	995	185	179	101
Drinking water supply	1	0	0	0
Energy sector	11,085	14,676	11,069	9,990
Mobility and transport	2,271	1,514	1,549	1,792
Nature	0	0	0	0
Other industry	732	556	408	379
Refineries	8,600	9,631	9,836	9,226
Sewage treatment	32	39	39	42
Trade, services and government	617	403	880	766
Waste disposal	1,641	1,456	1,729	1,767
Total	**29,129**	**32,166**	**28,834**	**26,991**

Table 103 - CO_2-eq. North Sea Port by source

Kton CO_2-eq.	2010	2015	2019	2020
Agriculture	7	3	3	2
Chemical industry	5801	5221	5787	6772
Construction	7	2	1	1
Consumers	153	26	25	25
Drinking water supply	0	0	0	0
Energy sector	5747	4060	1725	1799
Mobility and transport	366	237	269	281
Nature	0	0	0	0
Other industry	485	273	295	292
Refineries	1394	1543	1589	1167
Sewage treatment	6	8	8	8
Trade, services and government	51	25	24	23
Waste disposal	20	26	20	19
Total	**14,037**	**11,423**	**9,746**	**10,389**

B.2 Emissions of air quality pollutants by source

Table 104 – $PM_{2,5}$ emissions Port of Amsterdam by source

Kton $PM_{2,5}$	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.00	0.04	0.03	0.03
Construction	0.01	0.01	0.01	0.02
Consumers	0.20	0.12	0.13	0.10
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.04	0.05	0.01	0.00
Mobility and transport	0.15	0.12	0.13	0.10
Nature	-	-	-	-
Other industry	0.03	0.04	0.04	0.04
Refineries	-	-	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.04	0.04	0.03	0.03
Waste disposal	0.02	0.03	0.01	0.01
Total	**0.49**	**0.45**	**0.39**	**0.33**

Table 105 – $PM_{2,5}$ emissions Groningen Seaports by source

Kton $PM_{2,5}$	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.02	0.02	0.02	0.02
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.02	0.01	0.01
Drinking water supply	-	-	-	-
Energy sector	0.00	0.03	0.03	0.01
Mobility and transport	0.02	0.02	0.01	0.01
Nature	-	-	-	-
Other industry	0.06	0.03	0.08	0.03
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.01	0.01
Total	**0.12**	**0.12**	**0.16**	**0.09**

Table 106 – $PM_{2,5}$ emissions Port of Moerdijk by source

Kton $PM_{2,5}$	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.14	0.01	0.02	0.03
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.01	0.01	0.01
Drinking water supply	-	-	-	-
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.04	0.03	0.03	0.02
Nature	-	-	-	-
Other industry	0.01	0.03	0.02	0.03
Refineries	-	-	-	-
Sewage treatment	-	-	-	-

Kton $PM_{2,5}$	2010	2015	2019	2020
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.01	0.01	0.01	0.01
Total	**0.22**	**0.09**	**0.10**	**0.11**

Table 107 – $PM_{2,5}$ emissions Port of Rotterdam by source

Kton $PM_{2,5}$	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.03	0.05	0.03	0.02
Construction	0.02	0.02	0.02	0.02
Consumers	0.29	0.19	0.18	0.15
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.03	0.05	0.02	0.02
Mobility and transport	0.74	0.55	0.47	0.50
Nature	-	-	-	-
Other industry	0.12	0.14	0.10	0.10
Refineries	0.20	0.23	0.17	0.15
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.08	0.09	0.09	0.09
Waste disposal	0.00	0.00	0.01	0.01
Total	**1.51**	**1.32**	**1.10**	**1.06**

Table 108 – $PM_{2,5}$ emissions North Sea Port by source

Kton $PM_{2,5}$	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.51	0.41	0.31	0.21
Construction	0.00	0.00	0.00	0.00
Consumers	0.05	0.05	0.04	0.04
Drinking water supply	-	-	-	-
Energy sector	0.02	0.02	0.00	0.00
Mobility and transport	0.21	0.15	0.14	0.14
Nature	-	-	-	-
Other industry	0.19	0.07	0.02	0.02
Refineries	0.00	0.01	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.01	0.02	0.01
Waste disposal	0.00	0.00	0.00	0.00
Total	**1.00**	**0.72**	**0.55**	**0.44**

Table 109 – PM_{10} emissions Port of Amsterdam by source

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.00	0.02	0.01	0.01
Construction	0.02	0.00	0.00	0.00
Consumers	0.13	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.03	0.06	0.01	0.00
Mobility and transport	0.11	0.07	0.08	0.08

Kton PM_{10}	2010	2015	2019	2020
Nature	-	-	-	-
Other industry	0.05	0.08	0.10	0.11
Refineries	-	-	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.13	0.25	0.20	0.17
Waste disposal	0.01	0.04	0.01	0.01
Total	**0.48**	**0.52**	**0.42**	**0.38**

Table 110 – PM_{10} emissions Groningen Seaports by source

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.01	0.00	0.00	0.00
Chemical industry	0.04	0.05	0.04	0.04
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.00	0.05	0.04	0.01
Mobility and transport	0.02	0.01	0.01	0.01
Nature	-	-	-	-
Other industry	0.07	0.04	0.09	0.04
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.01	0.01
Total	**0.15**	**0.15**	**0.20**	**0.11**

Table 111 – PM_{10} emissions Port of Moerdijk by source

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.14	0.01	0.03	0.04
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.05	0.03	0.02	0.02
Nature	-	-	-	-
Other industry	0.02	0.04	0.03	0.03
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.01	0.01	0.01	0.01
Total	**0.23**	**0.09**	**0.10**	**0.11**

Table 112 – PM_{10} emissions Port of Rotterdam by source

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.03	0.08	0.04	0.03
Construction	0.05	0.02	0.02	0.02
Consumers	0.28	0.06	0.06	0.06
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.03	0.07	0.02	0.02
Mobility and transport	0.72	0.45	0.41	0.46
Nature	-	-	-	-
Other industry	0.34	0.24	0.15	0.14
Refineries	0.24	0.27	0.22	0.19
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.44	0.55	0.52	0.51
Waste disposal	0.00	0.00	0.01	0.01
Total	**2.13**	**1.73**	**1.45**	**1.42**

Table 113 – PM_{10} emissions North Sea Port by source

Kton PM_{10}	2010	2015	2019	2020
Agriculture	0.01	0.00	0.00	0.00
Chemical industry	0.52	0.56	0.38	0.28
Construction	0.01	0.00	0.00	0.00
Consumers	0.04	0.01	0.01	0.01
Drinking water supply	-	-	-	-
Energy sector	0.02	0.04	0.00	0.00
Mobility and transport	0.17	0.09	0.09	0.09
Nature	-	-	-	-
Other industry	0.21	0.10	0.05	0.05
Refineries	0.00	0.01	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.03	0.05	0.07	0.05
Waste disposal	0.00	0.00	0.00	0.00
Total	**1.02**	**0.87**	**0.61**	**0.48**

Table 114 – NO_x emissions Port of Amsterdam by source

Kton NO_x	2010	2015	2019	2020
Agriculture	0.03	0.00	0.00	0.00
Chemical industry	0.05	0.15	0.04	0.03
Construction	0.01	0.00	0.00	0.00
Consumers	0.27	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.41	0.86	0.78	0.24
Mobility and transport	2.68	2.16	3.07	2.80
Nature	0.00	0.00	0.00	0.00
Other industry	0.11	0.12	0.08	0.08
Refineries	0.00	-	0.03	0.04
Sewage treatment	0.00	0.00	0.01	0.01
Trade, services and government	0.18	0.04	0.02	0.02
Waste disposal	0.48	0.86	0.56	0.69
Total	**4.23**	**4.20**	**4.59**	**3.92**

Table 115 – NO_x emissions Groningen Seaports by source

Kton NO_x	2010	2015	2019	2020
Agriculture	0.08	0.02	0.02	0.02
Chemical industry	0.31	0.29	0.37	0.55
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	3.07	3.10	3.05	2.08
Mobility and transport	0.46	0.41	0.40	0.36
Nature	0.00	0.00	0.00	0.00
Other industry	0.04	0.03	0.04	0.03
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.01	0.03	0.02
Waste disposal	0.04	0.14	0.22	0.19
Total	**4.03**	**4.01**	**4.15**	**3.25**

Table 116 – NO_x emissions Port of Moerdijk by source

Kton NO_x	2010	2015	2019	2020
Agriculture	0.07	0.01	0.01	0.01
Chemical industry	1.70	0.65	1.07	1.30
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.44	0.39	0.32	0.23
Mobility and transport	1.00	0.67	0.55	0.52
Nature	0.00	0.00	0.00	0.00
Other industry	0.09	0.10	0.11	0.11
Refineries	0.00	-	-	-
Sewage treatment	0.00	-	-	-
Trade, services and government	0.01	0.00	0.00	0.00
Waste disposal	0.63	0.61	0.60	0.53
Total	**3.96**	**2.44**	**2.67**	**2.72**

Table 117 – NO_x emissions Port of Rotterdam by source

Kton NO_x	2010	2015	2019	2020
Agriculture	0.81	0.04	0.02	0.02
Chemical industry	1.46	1.45	1.09	0.96
Construction	0.02	0.01	0.01	0.01
Consumers	0.49	0.07	0.06	0.03
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	4.18	4.28	3.28	2.90
Mobility and transport	15.72	13.39	13.34	15.79
Nature	0.00	0.00	0.00	0.00
Other industry	0.98	1.14	0.72	0.58
Refineries	4.18	4.69	4.70	4.01
Sewage treatment	0.02	0.03	0.02	0.03
Trade, services and government	0.36	0.17	0.23	0.25
Waste disposal	0.45	0.53	0.54	0.54
Total	**28.67**	**25.80**	**24.00**	**25.13**

Table 118 – NO_x emissions North Sea Port by source

Kton NO_x	2010	2015	2019	2020
Agriculture	0.12	0.03	0.03	0.03
Chemical industry	2.49	2.61	2.86	2.74
Construction	0.00	0.00	0.00	0.00
Consumers	0.07	0.01	0.01	0.01
Drinking water supply	0.00	-	-	-
Energy sector	1.47	1.30	0.67	0.65
Mobility and transport	3.52	2.86	3.22	3.45
Nature	0.00	0.00	0.00	0.00
Other industry	0.27	0.14	0.33	0.12
Refineries	0.40	0.50	0.52	0.40
Sewage treatment	0.00	0.01	0.01	0.01
Trade, services and government	0.02	0.01	0.01	0.01
Waste disposal	0.01	0.01	0.01	0.01
Total	**8.38**	**7.48**	**7.66**	**7.43**

Table 119 – SO_2 emissions Port of Amsterdam by source

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.01	0.01	0.02	0.02
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.43	0.80	0.37	0.00
Mobility and transport	0.16	0.12	0.14	0.11
Nature	0.00	-	-	-
Other industry	0.02	0.00	0.00	0.00
Refineries	0.00	-	0.00	0.01
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.00	0.00	0.00
Waste disposal	0.05	0.06	0.01	0.02
Total	**0.69**	**0.99**	**0.55**	**0.16**

Table 120 – SO_2 emissions Groningen Seaports by source

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.47	0.43	0.40	0.30
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.01	0.73	0.66	0.42
Mobility and transport	0.08	0.02	0.02	0.01
Nature	0.00	-	-	-
Other industry	0.88	0.32	1.09	0.96
Refineries	0.00	-	-	-
Sewage treatment	0.00	-	-	-
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.01	0.02	0.01	0.01
Total	**1.44**	**1.52**	**2.18**	**1.71**

Table 121 – SO_2 emissions Port of Moerdijk by source

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.36	0.05	0.09	0.13
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.01	0.00	0.00	0.00
Mobility and transport	0.01	0.00	0.00	0.00
Nature	0.00	-	-	-
Other industry	0.07	0.12	0.13	0.15
Refineries	0.00	-	-	-
Sewage treatment	0.00	-	-	-
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.11	0.05	0.06	0.06
Total	**0.56**	**0.22**	**0.27**	**0.34**

Table 122 – SO_2 emissions Port of Rotterdam by source

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.99	0.92	0.80	0.90
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.00	0.00	0.00
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	1.98	2.80	0.53	0.39
Mobility and transport	2.00	0.56	0.53	0.59
Nature	0.00	-	-	-
Other industry	0.69	1.14	0.72	0.48
Refineries	11.53	9.11	7.09	6.10
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.02	0.04	0.03
Waste disposal	0.01	0.01	0.02	0.03
Total	**17.23**	**14.57**	**9.74**	**8.52**

Table 123 – SO_2 emissions North Sea Port by source

Kton SO_2	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.07	0.01	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	0.00	-	-	-
Energy sector	0.86	0.64	0.00	0.00
Mobility and transport	0.97	0.11	0.13	0.12
Nature	0.00	-	-	-
Other industry	1.15	0.02	0.15	0.31
Refineries	1.08	2.01	1.62	1.11
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.00	0.00
Total	**4.13**	**2.80**	**1.89**	**1.55**

Table 124 - NH_3 emissions Port of Amsterdam by source

Kton NH_3	2010	2015	2019	2020
Agriculture	0.01	0.01	0.01	0.01
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.00	0.00	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.02	0.02	0.02
Total	**0.05**	**0.05**	**0.05**	**0.05**

Table 125 - NH_3 emissions Groningen Seaports by source

Kton NH_3	2010	2015	2019	2020
Agriculture	0.06	0.05	0.04	0.04
Chemical industry	0.00	0.02	0.01	0.01
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.00	0.01	0.03	0.03
Mobility and transport	0.00	0.00	0.00	0.00
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.00	0.00
Total	**0.07**	**0.08**	**0.08**	**0.08**

Table 126 - NH_3 emissions Port of Moerdijk by source

Kton NH_3	2010	2015	2019	2020
Agriculture	0.06	0.03	0.04	0.04
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.01	0.01	0.01	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.01	0.03	0.02	0.02
Total	**0.08**	**0.08**	**0.08**	**0.08**

Table 127 – NH_3 emissions Port of Rotterdam by source

Kton NH_3	2010	2015	2019	2020
Agriculture	0.06	0.02	0.01	0.02
Chemical industry	0.00	0.01	0.02	0.02
Construction	0.00	0.00	0.00	0.00
Consumers	0.07	0.06	0.07	0.07
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.00	0.00	0.01	0.02
Mobility and transport	0.07	0.05	0.06	0.07
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.01	0.00	0.00
Refineries	0.00	0.00	0.01	0.01
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.02	0.02	0.02	0.02
Waste disposal	0.02	0.04	0.03	0.03
Total	**0.25**	**0.22**	**0.24**	**0.26**

Table 128 – NH_3 emissions North Sea Port by source

Kton NH_3	2010	2015	2019	2020
Agriculture	0.23	0.09	0.09	0.09
Chemical industry	0.27	0.45	0.26	0.32
Construction	0.00	0.00	0.00	0.00
Consumers	0.02	0.01	0.01	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	0.00	0.00	0.00	0.00
Other industry	0.00	0.00	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.01	0.01
Total	**0.54**	**0.56**	**0.39**	**0.44**

Table 129 – PB emissions Port of Amsterdam by source

Ton PB	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.01	0.01	0.01	0.01
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.01	0.01	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.03	0.03	0.02	0.02
Nature	-	-	-	-
Other industry	0.00	0.00	0.00	0.00
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.04	0.04	0.04	0.05
Total	**0.09**	**0.08**	**0.08**	**0.09**

Table 130 – PB emissions Groningen Seaports by source

Ton PB	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.01	0.01	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.00	0.00	0.00	0.00
Nature	-	-	-	-
Other industry	0.07	0.00	0.06	0.07
Refineries	-	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.01	0.01	0.01
Total	**0.08**	**0.01**	**0.07**	**0.08**

Table 131 – PB emissions Port of Moerdijk by source

Ton PB	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	-	-	-	-
Mobility and transport	0.01	0.00	0.01	0.01
Nature	-	-	-	-
Other industry	0.00	0.05	0.36	0.97
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.06	0.01	0.02	0.02
Total	**0.07**	**0.07**	**0.38**	**0.99**

Table 132 – PB emissions Port of Rotterdam by source

Ton PB	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	0.01	0.01	0.01	0.01
Construction	0.00	0.00	0.00	0.00
Consumers	0.01	0.01	0.01	0.01
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.01	0.00	0.00	0.00
Mobility and transport	0.05	0.05	0.05	0.06
Nature	-	-	-	-
Other industry	0.56	0.52	0.00	0.00
Refineries	0.01	0.01	0.01	0.01
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.06	0.01	0.02	0.02
Total	**0.71**	**0.60**	**0.10**	**0.10**

Table 133 - PB emissions North Sea Port by source

Ton PB	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	2.96	0.03	0.00	0.00
Construction	0.00	0.00	0.00	0.00
Consumers	0.00	0.00	0.00	0.00
Drinking water supply	-	-	-	-
Energy sector	0.00	0.00	0.00	0.00
Mobility and transport	0.01	0.01	0.01	0.01
Nature	-	-	-	-
Other industry	0.02	0.01	0.00	0.00
Refineries	0.00	0.00	0.00	0.00
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.00	0.00	0.00	0.00
Total	**2.99**	**0.05**	**0.01**	**0.01**

Table 134 - CO emissions Port of Amsterdam by source

Kton CO	2010	2015	2019	2020
Agriculture	0.01	0.00	0.00	0.00
Chemical industry	0.03	0.09	0.08	0.08
Construction	0.00	0.00	0.00	0.00
Consumers	2.16	1.04	0.98	0.69
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	0.25	0.37	0.33	0.02
Mobility and transport	9.32	8.34	7.28	6.11
Nature	0.02	0.02	0.02	0.02
Other industry	0.18	0.17	0.19	0.19
Refineries	-	-	0.01	0.01
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.12	0.11	0.09	0.08
Waste disposal	0.15	0.14	0.05	0.12
Total	**12.24**	**10.29**	**9.05**	**7.34**

Table 135 - CO emissions Groningen Seaports by source

Kton CO	2010	2015	2019	2020
Agriculture	0.01	0.01	0.01	0.01
Chemical industry	0.58	0.58	0.39	0.44
Construction	0.00	0.00	0.00	0.00
Consumers	0.14	0.18	0.16	0.13
Drinking water supply	-	-	-	-
Energy sector	0.30	1.20	0.55	0.66
Mobility and transport	0.44	0.41	0.36	0.30
Nature	0.04	0.03	0.03	0.03
Other industry	7.65	1.98	8.66	7.19
Refineries	-	-	-	-
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.01	0.04	0.04	0.05
Total	**9.16**	**4.45**	**10.20**	**8.82**

Table 136 – CO emissions Port of Moerdijk by source

Kton CO	2010	2015	2019	2020
Agriculture	0.01	0.01	0.01	0.01
Chemical industry	0.23	0.29	0.16	0.91
Construction	0.00	0.00	0.00	0.00
Consumers	0.13	0.14	0.12	0.12
Drinking water supply	-	-	-	-
Energy sector	0.04	0.03	0.05	0.05
Mobility and transport	1.34	1.12	0.93	0.87
Nature	0.06	0.05	0.05	0.05
Other industry	0.03	0.04	0.05	0.04
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	0.00	0.00	0.00	0.00
Waste disposal	0.19	0.15	0.11	0.12
Total	**2.04**	**1.84**	**1.49**	**2.18**

Table 137 – CO emissions Port of Rotterdam by source

Kton CO	2010	2015	2019	2020
Agriculture	0.51	0.41	0.48	0.46
Chemical industry	3.10	3.06	2.89	2.78
Construction	0.01	0.01	0.01	0.01
Consumers	3.27	1.79	1.64	1.27
Drinking water supply	0.00	0.00	0.00	0.00
Energy sector	1.17	0.59	0.67	0.56
Mobility and transport	20.34	16.80	14.84	15.00
Nature	0.10	0.09	0.09	0.09
Other industry	2.32	0.40	0.28	0.28
Refineries	5.74	4.90	2.13	1.98
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.17	0.14	0.13	0.12
Waste disposal	0.23	0.18	0.17	0.19
Total	**36.95**	**28.37**	**23.33**	**22.74**

Table 138 – CO emissions North Sea Port by source

Kton CO	2010	2015	2019	2020
Agriculture	0.00	0.00	0.00	0.00
Chemical industry	4.14	4.58	6.51	2.94
Construction	0.00	0.00	0.00	0.00
Consumers	0.61	0.55	0.49	0.46
Drinking water supply	-	-	-	-
Energy sector	0.61	0.50	0.12	0.10
Mobility and transport	2.72	2.43	2.15	2.00
Nature	0.16	0.14	0.14	0.14
Other industry	1.11	0.19	0.12	0.16
Refineries	0.52	0.66	0.47	0.48
Sewage treatment	0.00	0.00	0.00	0.00
Trade, services and government	0.01	0.01	0.01	0.01
Waste disposal	0.03	0.03	0.04	0.05
Total	**9.91**	**9.10**	**10.07**	**6.34**

Table 139 - Benzopyrene emissions Port of Amsterdam by source

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	-	-	-	-
Construction	0.000	0.000	0.000	0.000
Consumers	0.039	0.019	0.018	0.015
Drinking water supply	0.000	0.000	-	-
Energy sector	0.001	0.002	0.002	0.001
Mobility and transport	0.003	0.003	0.003	0.003
Nature	-	-	-	-
Other industry	0.000	0.000	0.000	0.000
Refineries	-	-	-	-
Sewage treatment	0.000	0.000	0.000	0.000
Trade, services and government	0.000	0.000	0.001	0.001
Waste disposal	0.000	0.000	0.000	0.000
Total	**0.043**	**0.025**	**0.024**	**0.020**

Table 140 - Benzopyrene emissions Groningen Seaports by source

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	-	0.004	0.004	0.004
Construction	0.000	0.000	0.000	0.000
Consumers	0.002	0.003	0.003	0.002
Drinking water supply	-	-	-	-
Energy sector	0.000	0.003	0.004	0.003
Mobility and transport	0.000	0.000	0.000	0.000
Nature	-	-	-	-
Other industry	0.000	0.000	0.000	0.000
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	0.000	0.000	0.000	0.000
Waste disposal	0.000	-	-	-
Total	**0.003**	**0.011**	**0.012**	**0.010**

Table 141 - Benzopyrene emissions Port of Moerdijk by source

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	-	-	-	-
Construction	0.000	0.000	0.000	0.000
Consumers	0.002	0.003	0.002	0.002
Drinking water supply	-	-	-	-
Energy sector	-	-	0.001	-
Mobility and transport	0.001	0.001	0.001	0.001
Nature	-	-	-	-
Other industry	0.000	0.000	0.000	0.000
Refineries	-	-	-	-
Sewage treatment	-	-	-	-
Trade, services and government	0.000	0.000	0.000	0.000
Waste disposal	0.000	0.000	0.000	0.000
Total	**0.003**	**0.003**	**0.004**	**0.003**

Table 142 - Benzopyrene emissions Port of Rotterdam by source

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	0.003	-	-	-
Construction	0.000	0.000	0.000	0.000
Consumers	0.060	0.032	0.029	0.024
Drinking water supply	0.000	0.000	-	-
Energy sector	0.000	0.000	0.000	0.000
Mobility and transport	0.010	0.009	0.010	0.010
Nature	-	-	-	-
Other industry	0.010	0.007	0.003	0.003
Refineries	-	-	-	-
Sewage treatment	0.000	0.000	0.000	0.000
Trade, services and government	0.000	0.001	0.001	0.001
Waste disposal	-	-	-	-
Total	**0.083**	**0.049**	**0.043**	**0.038**

Table 143 - Benzopyrene emissions North Sea Port by source

Ton $C_{20}H_{12}$	2010	2015	2019	2020
Agriculture	0.000	0.000	0.000	0.000
Chemical industry	-	-	-	-
Construction	0.000	0.000	0.000	0.000
Consumers	0.011	0.010	0.009	0.009
Drinking water supply	-	-	-	-
Energy sector	0.000	0.000	0.000	0.000
Mobility and transport	0.002	0.002	0.002	0.002
Nature	-	-	-	-
Other industry	0.002	0.000	0.000	0.000
Refineries	0.007	-	-	-
Sewage treatment	0.000	0.000	0.000	0.000
Trade, services and government	0.000	0.000	0.000	0.000
Waste disposal	0.000	0.000	0.000	0.000
Total	**0.022**	**0.012**	**0.011**	**0.011**