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Root Cause Analysis for Air Quality Measurement Results of the EU-Life-Project „CLean INland Shipping" in NRW (Part 1)

Results for the Inland Port of Duisburg

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For the EU project CLean INland SHipping, LANUV NRW has carried out intensive investigations on NO_X emissions from shipping traffic and port operations on the North Rhine-Westphalian section of the Rhine. Based on the results, air pollution (NO_2) in large inland ports can be better specified. In addition, new methods for recording NO_X emissions from moored and moving ships were developed. The results allow an improved analysis of the air pollution contributions of the different NO_X emission sources. Directly at the Rhine, the EU limit value of NO_2 (40 µg/m³, annual mean) was complied with. The contribution of shipping traffic to the air pollution in the residential areas of the cities along the Rhine is lower than assumed. A more detailed description of the aspects of the individual CLINSH activities from NRW can be found in the German or English language reports of the LANUV NRW [1a,b–6a,b].

1. Introduction

In the Federal State of North Rhine-Westphalia (NRW), eleven major cities with approx. 3.3 million inhabitants are directly located along the Rhine. For a long time, in many cities the limit values of the EU Air Quality Directive for NO_2 (annual mean 40 µg/m³) could not be complied with due to the high traffic load. In 2020, for the first time, the EU limit values for NO_2 were complied with at all measuring points of the state measuring network in NRW. Despite the ongoing improvement in air quality in North Rhine-Westphalia in recent years, compliance with the binding limit values of the EU Air Quality Directive still remains a challenge.

Also the emissions from inland waterway vessels are a significant source of air pollution for municipalities along waterways. However, there was still room for improvement in the description of inland waterway vessel emissions at the beginning of the CLINSH project. Therefore, the LANUV investigated NO_2 pollution of the air on the Rhine and in the ports of Duisburg and Neuss/Düsseldorf at more than 50 measuring sites. Overall, it was found that the annual mean NO_2 concentrations measured at the CLINSH monitoring sites were significantly lower than expected. This was particularly true for the measuring points on the Rhine, which were directly influenced by the emissions from approx. 80,000 ships per year **(LANUV-CLINSH-report part D [4])**. In part one of this publication, the results of the cause analyses on air pollution of the Duisburg port area are presented. The results for the Neuss port area will be published as part 2 in one of the next issues.

In **Fig. 1** the classified measuring results (2018) of NO_2 from the research area of Duisburg are shown. Not only the absolute level of NO_2 pollution in the air was of interest to CLINSH. A special focus was placed on the investigation of the pollution shares of inland waterway traffic and port operations. For this purpose, the contributions of the different emission sources to the air pollution were intensively analyzed.

This is followed by a comparison of the measurement results from 2018 with the immission concentrations modelled at the respective measurement site. The modelled and measured NO_X annual mean values are compared. Subsequently, an analysis of the observed deviations between modelling and measurement is carried out.

2. Setup of the dispersion modelling

The dispersion modelling for the root cause analysis of air quality measurements was performed using the Lagrangian particle model LASAT **[7]**, in which the path of virtual particles is traced. The calculations include the use of the PLURIS model integrated in LASAT to calculate plume rise from hot and impulsive sources.

2.1 Model area and spatial resolution

LASAT allows the use of several grid levels with different spatial resolutions to cover a large model area on the one hand and to choose a finer grid resolution and thus more detailed analyses in the areas of interest on the other hand. In this study, dispersion modelling is carried out on six nested grid levels.

The largest model area has an extension of about 25 km × 41 km with a spatial resolution of 160 m. It includes the two port areas of Duisburg and Neuss and their vicinity with a radius of at least 5 km each. Five further model levels are each nested down to the port areas of Duisburg and Neuss, with the extent of the grids decreasing and the grid width halving with each level. At the innermost grid level with a spatial resolution of 5 m, three (resp. two) model areas are located next to each other in the port area of Duisburg (resp. Neuss) in order to cover the port areas with a sufficiently high resolution as extensively as possible.

2.2 Effects of terrain and buildings

Fig. 2 shows the terrain relief in the model area as well as the nested model grids in the vicinity of the Duisburg (solid) and Neuss (dashed) port areas and the anemometer posi-

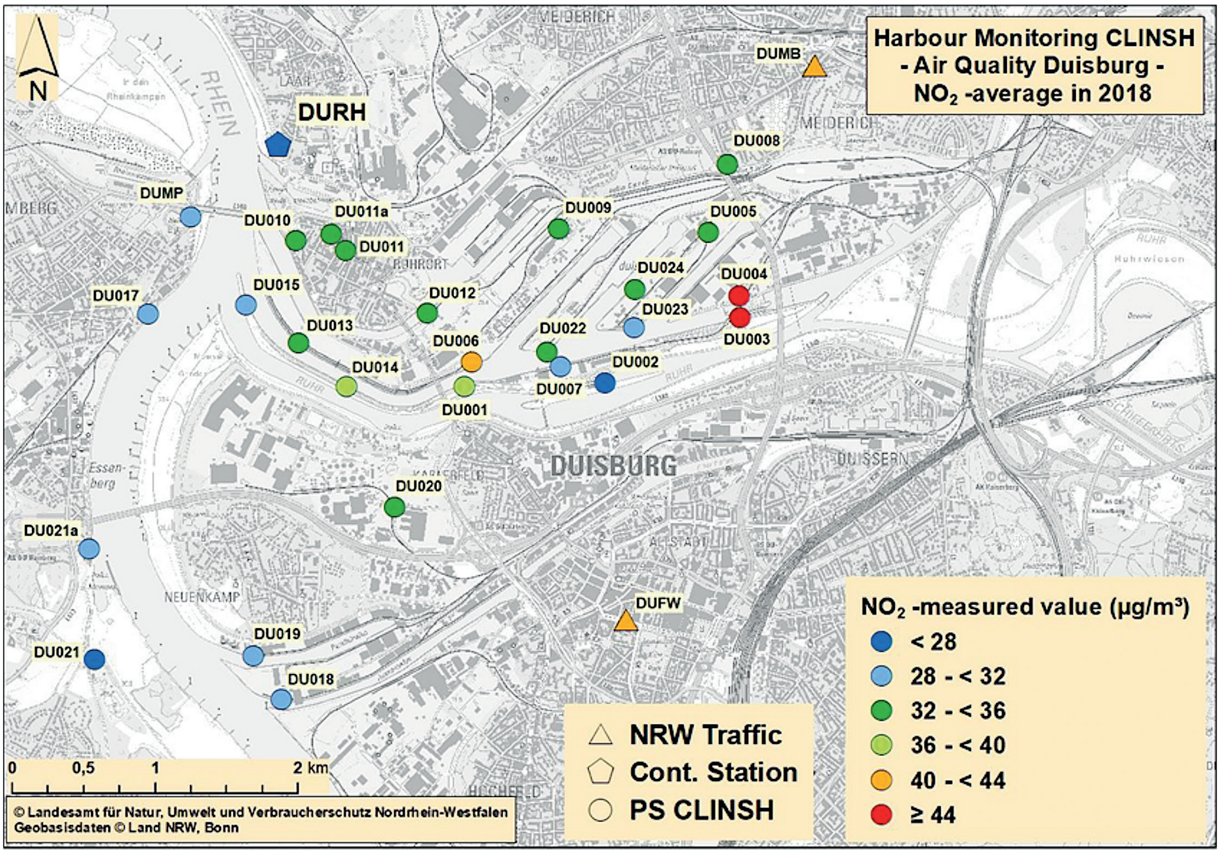


Fig. 1: NO_2 air pollution in the port of Duisburg – classified annual mean values 2018

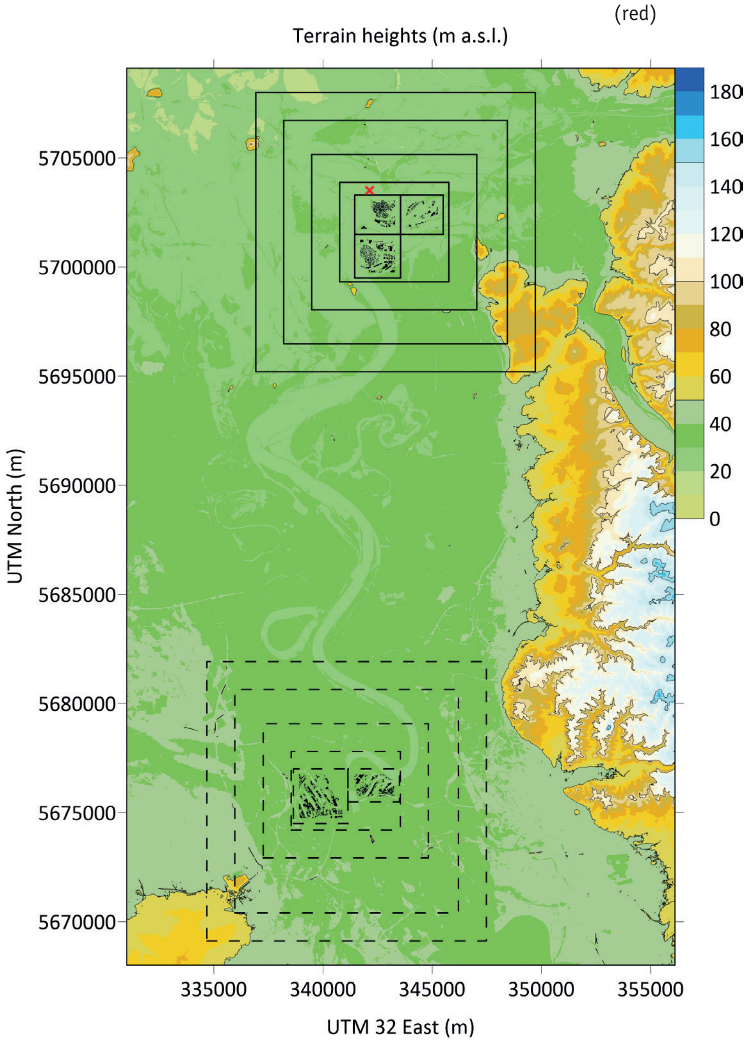


Fig. 2: Terrain heights (m a.s.l.) in the LASAT total area with the location of the nested model grids for Duisburg (solid) and Neuss (dashed) and anemometer position (red)

tion. The terrain elevations vary between 20 m and 50 m throughout most of the total area. The highest elevation is about 175 m at the eastern border of the model area south of the Ruhr River.

Buildings can significantly affect the atmospheric dispersion of trace substances, which is especially true for large buildings near the measuring sites. For that reason, the model calculations are carried out with diagnostic wind field modelling taking into account all buildings highlighted in black in **Fig. 2** within the innermost grids in the port areas.

In addition, the Rhine valley can also influence the flow conditions and thus the dispersion of emissions in the port areas. Since in particular, the smaller-scale terrain structures, such as embankments in the port area, can also be relevant for the dispersion of emissions near to the sources, the model calculations are carried out including the terrain effects in the entire model area.

2.3 Emissions in the investigation area

The NO_x emissions of all emitter groups in the considered study area are summarized in the following table **(Tab. 1)**. A detailed summary of emissions for the two port areas can be found in the **LANUV-CLINSH-report part E [5]**. In the LASAT model calculations, NO_x emissions from six polluter groups were specified separately, where each polluter group might consist of multiple polluters and source types. **Tab. 1** shows an overview of the pollution emitter groups and source types of the applied emissions. The largest share of NO_x emissions (64 %) is caused by industrial facilities requiring permits. They are predominantly released via chimneys at higher altitudes and therefore have almost no significant effect at ground level around the plants. The share

Emitter group	NO_x Emissions [t/a]	Emission share	Emitter	LASAT Source type
Shipping traffic	3,252	11%	Tanker at berth – harbour	Point sources
			All other ships at berth – harbour	Line sources
			Ships traveling to the locks	Line sources
			Ships in the locks	Line sources
			Ships travelling – harbour	Line sources
			Ships travelling – Rhine	Line sources
Road traffic	4,971	16%	Road traffic	Line sources
Industrial	19,511	64%	Plants requiring approval	Point sources
Rail transport incl. port railway	330	1%	Port railway	Line sources
			DB railway	Line sources
			Shunting Operations	Area sources
Air traffic	913	3%		Area sources (1 km² raster)
Off-road traffic	408	1%		Area sources (1 km² raster)
HUK (small combustion plants, domestic heating)	1,151	4%		Area sources (1 km² raster)
total	30,536	100%		

Tab. 1: NO_x emitter groups and source types of the applied emissions – analysis year 2018

of road traffic (ground level emission release) in the total load is 16 % and that of shipping 11 %. In contrast, all other emitter groups (air traffic, off-road and small combustion plants) only contribute a maximum of 4 % to the total NO_x emissions. Emissions are released from line and point sources as well as area sources throughout the model area.

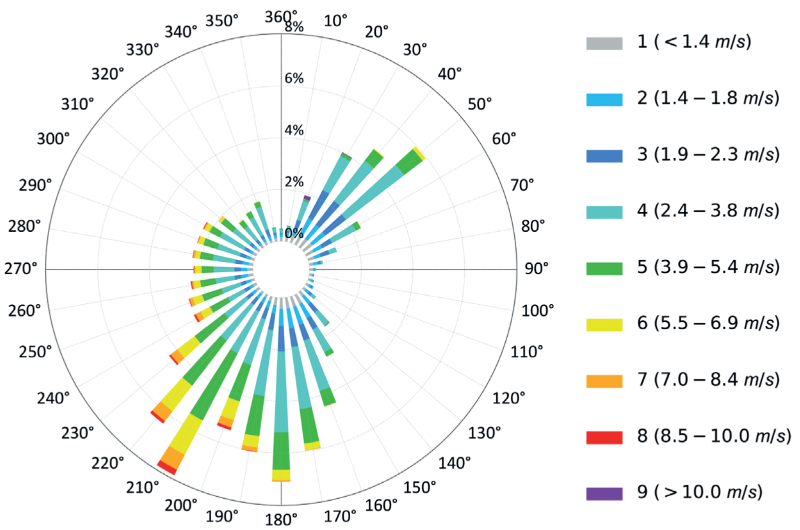
2.4 Splitted dispersion simulation

At the finest grid level, the buildings in the port areas of Duisburg and Neuss are taken into account. However, this means that area sources in the finest grids would partly be located within cells of the buildings. To be able to consider dispersion from line and point sources between buildings and to account for area emissions, which overlap grid cells with building, a splitted dispersion modelling approach is pursued.

In a first calculation, no buildings are considered and emissions from area sources are released within the entire model area. In addition, all emissions from point and line sources outside the finest grid areas are released. In a second calculation, buildings are explicitly considered and only emissions from point and line sources within the finest grid areas are released. Finally, concentrations from both calculations are summed up on all grid layers.

Only one roughness length can be applied to the entire LASAT model area. In the first calculation, this roughness length has to account for the frictional drag of buildings on the atmosphere. In the second calculation, this frictional drag is explicitly simulated. Thus, a lower roughness length has to be applied in this case. In the calculations where the buildings are not modelled even within the finest areas, the roughness length is set to $z_0 = 0.5$ m according to the LBM classes for the model area. In cases where buildings in the port areas of Duisburg and Neuss are explicitly modelled, a different roughness length must be applied to the model area. Otherwise, the influence of the buildings would be taken into account via the roughness length as well as the explicitly modelled buildings and would thus be imposed "twice". For the model calculations with buildings, a roughness length corresponding to the LBM classes of $z_0 = 0.2$ m is applied. Detailed information on this approach can be found in the **LANUV-CLINSH-report part F [6]**.

Fig. 3: Distribution of wind direction and wind speed at Duisburg-Rheinhafen measuring station (DURH) – measuring period 2018–2020



2.5 Meteorological forcing data

The dispersion calculations are performed involving modelling of the terrain. Therefore, a suitable meteorological forcing data set has to be found. In the entire model area of the dispersion calculations, there are one measuring station of the German Weather Service (DWD) and eight measuring stations of the LANUV, at which meteorological data are also collected.

The comparison of measurements at these available stations and their review for suitability as meteorological forcing data can be found in **LANUV-CLINSH-report part F [6]**. After considering all the facts, the data from the "Duisburg-Rheinhafen" (DURH) station from 2018–2020 appear to be the most suitable for use as meteorological forcing data.

The data sheet of the measuring station "Duisburg-Rheinhafen" (DURH) for the period 2018–2020 **(Fig. 3)** shows a southwest maximum with a secondary maximum from the northeast. Both correspond approximately to the synoptic conditions in the region. The also increased frequencies around southerly wind directions could still be due to the course of the Rhine upstream. The measuring station DURH is located within the model domain; so that the meteorological forcing can be located at the site coordinates **(see Fig. 2)**.

3. NO_x immissions in the Duisburg port area – areal representation

The spatially computed NO_x total immission concentrations as well as the shares of port immissions (ships in port traffic, ships at berth and general port operations) and emissions from ships sailing on the Rhine are presented at the lowest model level, which roughly corresponds to an average height of 1.5 m above ground.

3.1 Consideration of a supra-regional background value

In the scope of the clean air planning, the LANUV has recommended a consistent approach to determine a resilient background pollution for the Rhineland. For the routine modelling of the LANUV, the background pollution "Rhineland" is defined as the mean value of six so-called "background measuring stations" that are not directly dominated by road traffic. In this study, the immissions of the different source groups are determined on a large scale within the entire study area. The estimate based on these background stations, all still containing large-scale immission components, appears to be too conservative. As part of the measurement program in Bimmen-Lobith (also part of the CLINSH-Project), the so-called rural background pollution was determined, which can largely be classified as unpolluted by other sources. In 2018, this value was approximately 14 µg/m³ (NO_2), which, taking into account a stoichiometric conversion corresponds to an annual mean value of 20 µg/m³ NO_x. This value was used in the determination of the total load in the modelling for the CLINSH-Project.

3.2 Modelling results of the total immissions

Fig. 4 shows the modelled total NO_x immissions for the port area of Duisburg. Clearly recognizable are the high local concentrations along the Rhine, along the harbour basins and along the road axes with high traffic, for example the BAB 40 (west–east) and the BAB 59 (north–south). Some strongly predominantly ground-level emitting sources also stand out clearly. However, the high NO_x immission level along the Rhine is dominant in the depicted study area.

3.2.1 Shipping traffic in the port, ships at berth and general port operations

Fig. 5 shows the share of NO_x immissions caused by port operations in the total NO_x load for the extended port area of Duisburg. A high NO_x immission share of almost 40 % to 50 % has been modelled along the fairways in the access to the port or in the port itself, which, however, decreases quite quickly with increasing distance from the respective fairway. In addition, locally very high NO_x immission concentrations has been modelled in the immediate vicinity of the tank depots in the area of the south bank of the Ruhr, in the area of the tank depots on the northern bank of the basin between the "coal island" and the "oil island", and further east in the lock area. These high NO_x concentrations are mainly caused by the unloading operations of the tankers, which are carried out with the onboard pumps or by the ships in lock operations with the main engine idling.

However, the NO_x immission concentrations also subside quite quickly. In the area of the harbour basins, the share of port immissions mainly ranges between 10 % and 20 %. However, at the periphery of the finely resolved harbour areas in the model, the share of NO_x immission concentrations due to the port operations is well below 10 %. On the north-

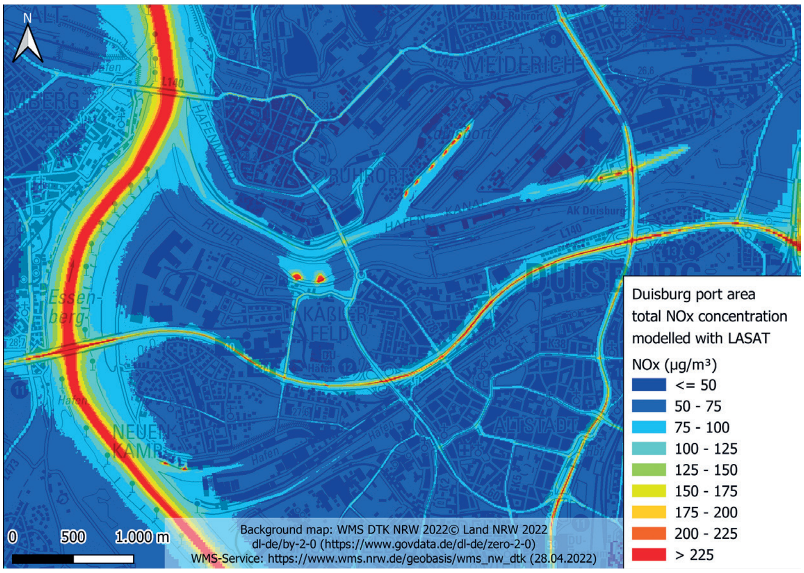


Fig. 4: Total NO_x immission in the Duisburg port area – modelled with LASAT

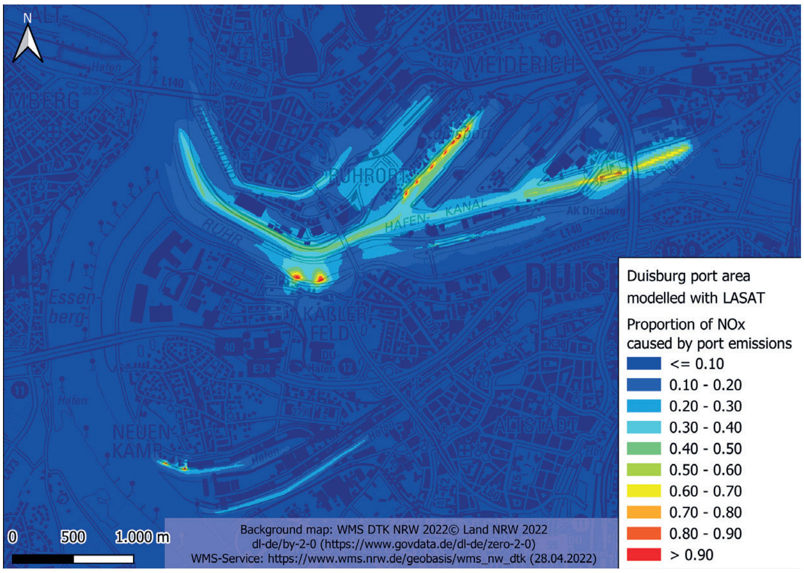


Fig. 5: Proportion of NO_x immission caused by port emissions in the Duisburg port area – modelled with LASAT (value of 1.0 corresponds to a share of 100%)

western boundary of the Duisburg urban area, the proportion of NO_x immissions lies at 5 % and below.

3.2.2 Ships on the Rhine

Fig. 6 shows the proportion of total NO_x immissions caused by shipping traffic on the Rhine for the extended port area of Duisburg. As expected, the highest NO_x immission concentrations are found along the shipping fairway. They account for 80–90 % of the total NO_x immissions. The proportion decreases to 70–80 % towards the shore area. With increasing distance to the Rhine, a further continuous decrease is to be expected. On the right bank of the Rhine, the proportion in the area of the nearest settlement "Laar" ranges from 30–40 % in the western part, while in the eastern part it is still 20–30 %. Up to the Duisburg city area, the share of immissions from ships on the Rhine in the total immissions decreases to about 10 % or less. On the left bank of the Rhine, the share attributable to Rhine shipping ranges between 30 % and 40 % in "Homberg" and between 20 % and 30 % in the "Hochemmerich" area.

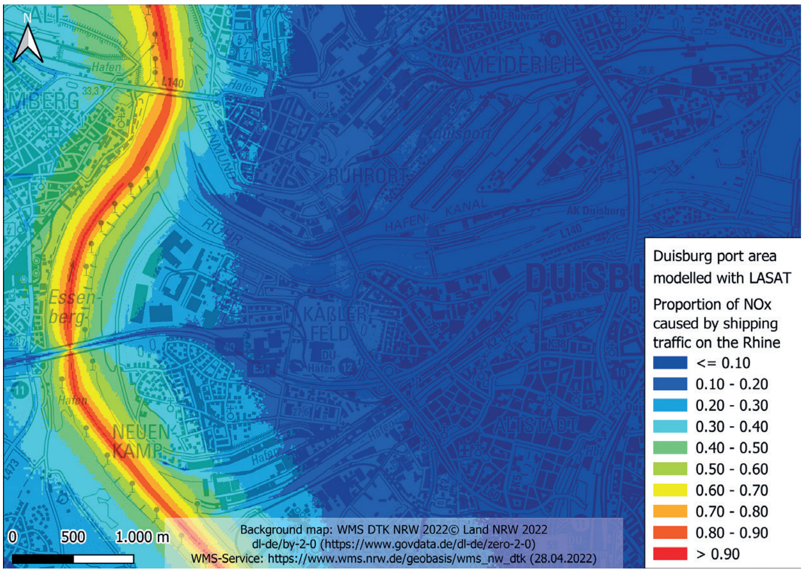


Fig. 6: Proportion of NO_X immission caused by shipping traffic on the Rhine in the Duisburg port area – modelled with LASAT (value of 1.0 corresponds to a share of 100 %)

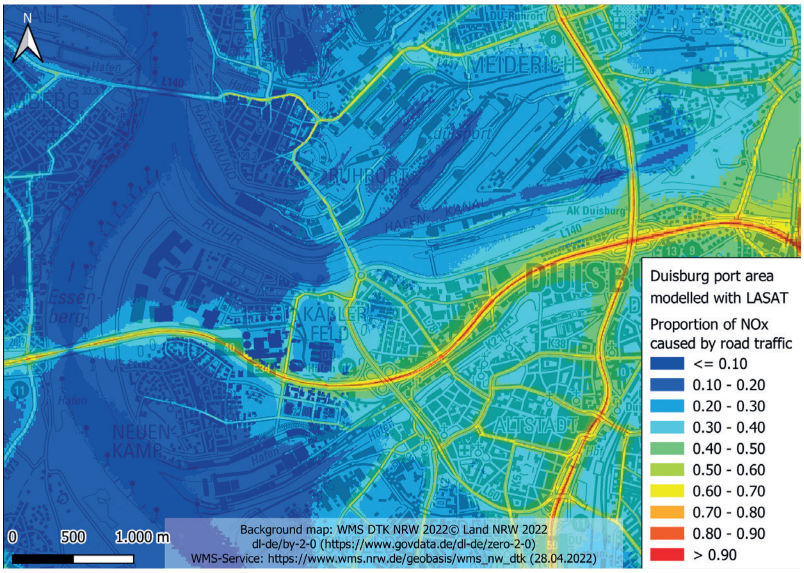


Fig. 7: Proportion of NO_X immission caused by road traffic in the Duisburg port area – modelled with LASAT (value of 1.0 corresponds to a share of 100 %)

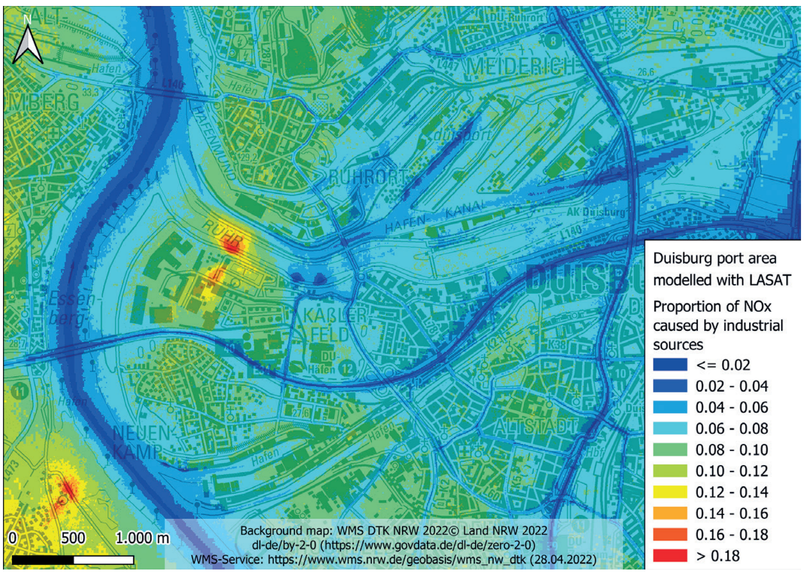


Fig. 8: Proportion of NO_X immission caused by industrial sources in the Duisburg port area – modelled with LASAT (value of 0.1 corresponds to a share of 10 %)

3.2.3 Road Traffic

Fig. 7 shows the share of NO_X immissions caused by road traffic in the total NO_X load for the extended port area of Duisburg. Very high shares can be seen along the roads, as is to be expected. In particular, the two highways BAB 40 and BAB 59 stand out strikingly. The shares decrease continuously with increasing distance from the roadways. In the port area, they range generally between 20 % and 30 %. In the area of the "Altstadt" (southeast of the harbour), with shares of 30 % and 40 %, it is evident that road traffic is the dominant source of NO_X pollution here.

3.2.4 Industry

In the 25 km × 41 km overarching study area, about 19,500 tons of NO_X were emitted from industrial facilities requiring permits in 2018. However, since these quantities are usually emitted via stacks at a higher altitude, their ground-level local effect on air quality in the study area remains rather low. **Fig. 8** shows the ground-level effect of industrial emissions in the Duisburg port area. In 2018, 1,277 tons NO_X were emitted by industrial sources in this area.

It must be noted that the scaling in **Fig. 8** differs from those of the other charts. In most settlement areas, the industrial polluter share is in the order of about 6 %–12 %. In a few places in the study area, there are locally limited higher impact shares of over 18 % (shown in red).

4. Conversion of the NO_2 measured values for comparison with the modelling results

The EU has set binding annual average limits for nitrogen dioxide (NO_2). The nitrogen oxide compounds in the exhaust gases of internal combustion engines essentially consist of a mixture of nitrogen monoxide (NO) and nitrogen dioxide. Directly at the exhaust pipe, NO predominates in diesel engines. The mixing ratio at the exhaust gas outlet into the atmosphere does not remain constant, but changes continuously in spatial and temporal terms. Shortly after the emission into the ambient air, a part of the NO load is converted to NO_2 due to air-chemical processes, whereby an interplay of different influencing factors (temperature, solar radiation, ozone concentrations, etc.) occurs. This interplay is individually dependent on the situation at the different measurement locations.

The polluter analyses, carried out as part of the CLINSH project, are also based on computations of this form and relate to nitrogen oxides (NO_X). In contrast, the passive samplers, the majority of the monitoring stations were equipped with, measure nitrogen dioxide (NO_2). In order to compare the measured values with the modelling results, the NO_2/NO_X conversion has to be taken into account. Therefore, NO_2 measurements were converted to NO_X.

The chemical conversion of NO_X to NO_2 is extremely complex and dependent on a number of parameters. In this study, the simplified Romberg approach with parameters according to **Schlamberger (2020) [8]** was used, which is based on current measurement data and thus implicitly integrates the ozone chemistry.

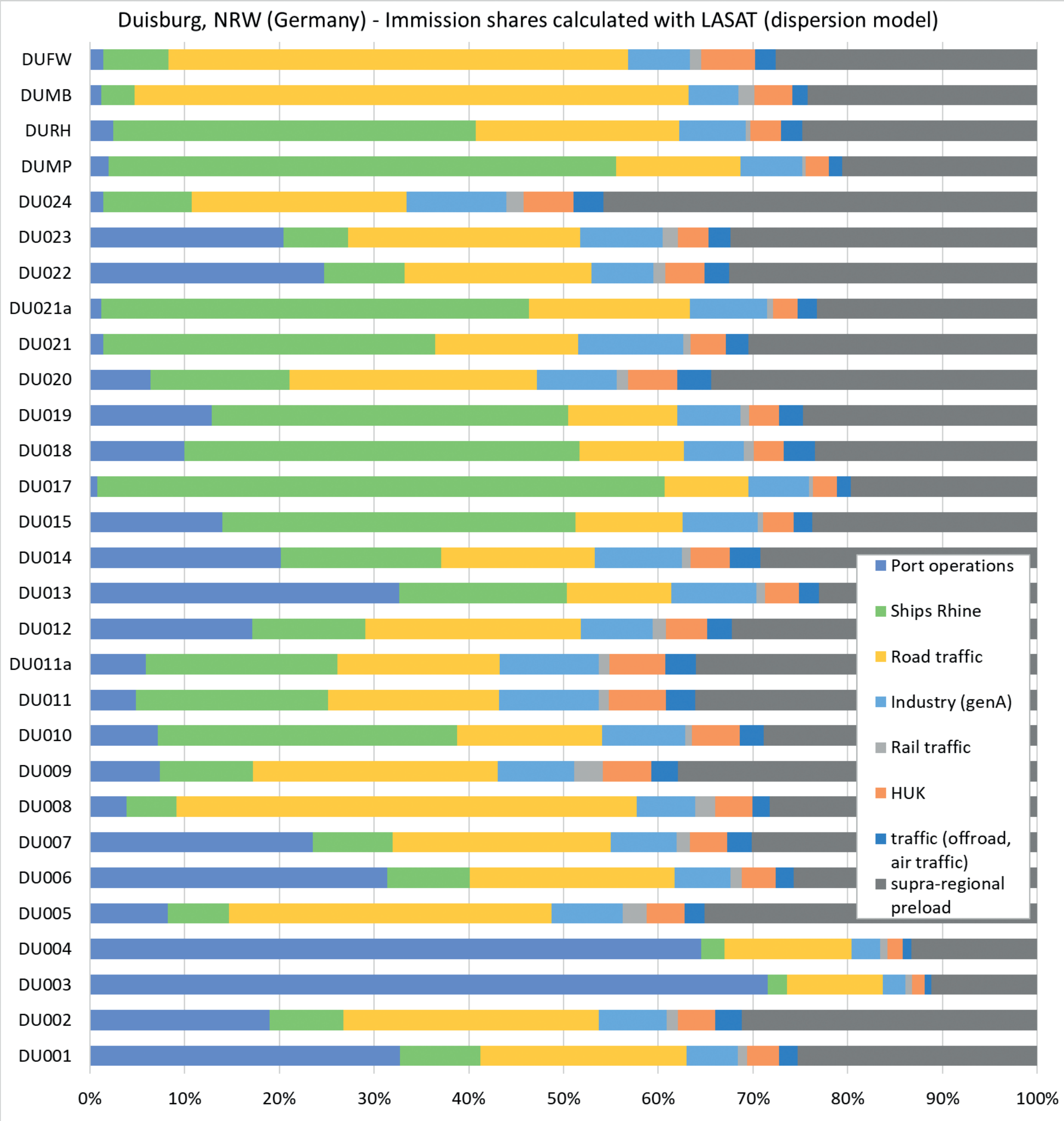


Fig. 9: NO_x source group percentages (Duisburg Harbour) – modelled with LASAT

5. Calculated source group percentages of NO_x immissions at the measuring sites

A polluter analysis was derived from the dispersion modelling for all measurement locations. The results of the polluter analyses for selected monitoring sites with different load structures are presented below. A detailed presentation of all sampling stations can be found in the **LANUV-CLINSH-report part F [6]**.

The NO_x shares in the total NO_x immission for the respective differentiated source groups were computed for each of the measuring sites. It is noticeable in the Duisburg port area **(Fig. 9)** that the immissions due to the industrial/commercial sources are in a range below 10 % of the total NO_x immissions at all measuring point locations. The NO_x immissions caused by HUK (small combustion plants and domestic heating) range from about 3 % to 6 % at almost all measuring points, the share caused by rail traffic amounts to a maximum of 3 %. The source group "other traffic" (off-road traffic and aviation) also has only small shares with a maximum of 4 %.

Large differences occur in the immission shares at the individual measuring point locations for the source groups ships on the Rhine, road traffic and ships in the port. Since these source groups are sources with low emission release heights, the proportions thus roughly reflect the location of the measuring point. For example, the measuring sites DU015, DU018 and DU019 and DURH (measuring points see **Fig. 1**) all show a high immission share due to shipping traffic on the Rhine. They are located on the right bank of the Rhine at a maximum distance of 200 m from the shore.

The stations DU017, DU021, DU021a and DUMP, which are all located on the left bank of the Rhine and partly even closer to the river bank, show even higher shares due to shipping traffic. The stations DU008 as well as DUMB and DUFW show relatively high contributions from road traffic. These are measuring stations in the immediate vicinity of roads with high levels of traffic. A very high proportion due to shipping traffic in the harbour area can be seen at measuring stations DU003, DU004 and, to a somewhat lesser extent, DU006 and DU013. These are all located close to harbour ba-

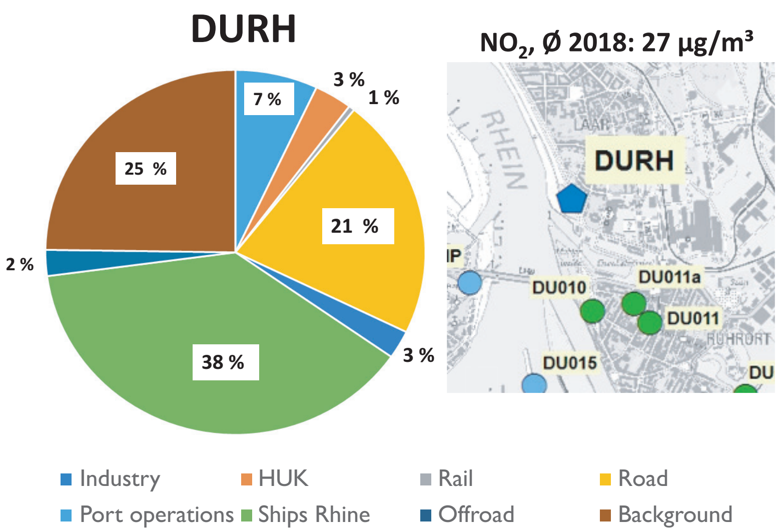


Fig. 10: Causation diagram for NO_x pollution at the automatic measuring station Duisburg-Rheinhafen (DURH) in 2018. The measured NO_2 concentration in 2018 (annual mean) was 27 µg/m³

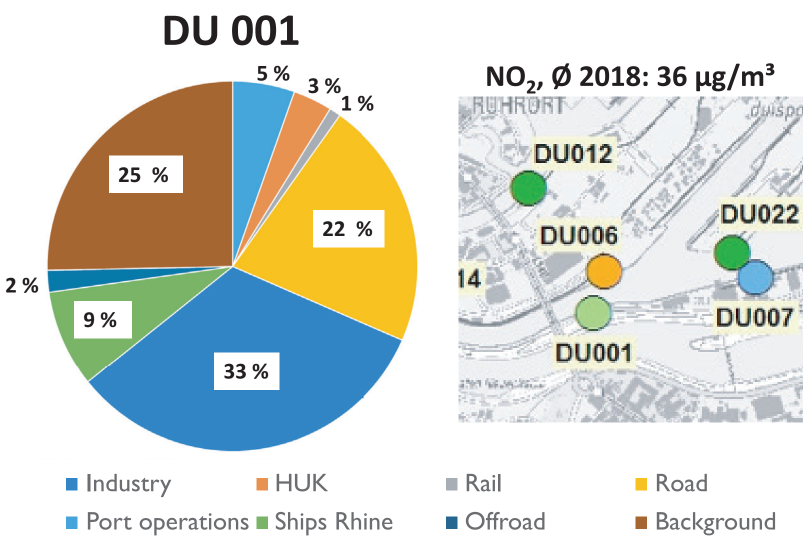


Fig. 11: Causation diagram for NO_x pollution at CLINSH monitoring station DU001 (harbor channel) in 2018. The measured NO_2 concentration (annual mean) was 36,4 µg/m³

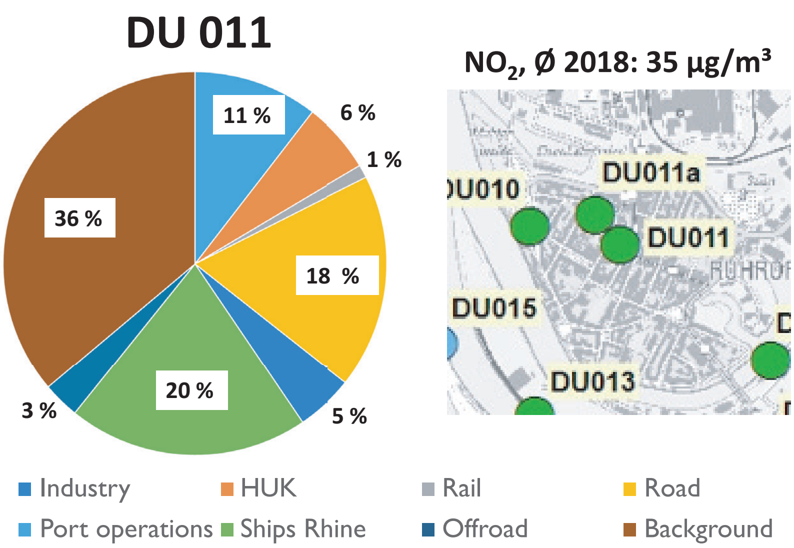


Fig. 12: Causation diagram for NO_x pollution at CLINSH monitoring station DU011 (residential area between the port and the Rhine) in 2018. The measured NO_2 concentration (annual mean) was 35.1 µg/m³

sins and/or landing stages or in the lock area. The percentage of regional background also varies accordingly; since the background concentration was considered constant for the whole study area, it also reflects the level of the measured total NO_x immission. As total measured concentrations at monitoring sites in the Duisburg modelling area increase, the percentage share of the constant background pollution decreases.

6. Source group shares of NO_x immissions at selected monitoring stations

In the following, the source group shares at individual selected measuring points are examined in more detail.

Fig. 10 shows the modelled pollution shares of the emitters at the CLINSH measuring station Duisburg-Rheinhafen (DURH, NO_2 annual mean 2018: 27 µg/m³). Here, the immission shares of ships sailing on the Rhine in the NO_x pollution are about 38 %. General "background pollution" (about 25 %) and road traffic in Duisburg (about 21 %) also contribute significant pollution shares. Emissions from ships in the port and from port operations play only a minor role at this station, accounting for about 2.5 % of pollution. The ground-level effects of the industrial emissions, present in the study area, also play a rather subordinate role with about 7 % load share of the NO_x immissions.

As expected, the measuring points located directly in the port have a high proportion of pollution caused by ships sailing and docking in the port area (port operations), including other emitters from general port operations. **Fig. 11** shows the respective load shares using the example of measuring site DU001 at the harbour (NO_2 annual mean 2018: 36.4 µg/m³). The port operations achieve a share of pollution (NO_x) of about 33 %, closely followed by the background pollution (22 %) and the Duisburg road traffic. The share of ships sailing on the Rhine still reaches 8.5 % at this measuring site.

Measuring station DU011 (NO_2 annual mean 2018: 35.1 µg/m³) is located in a quiet residential area with small residential streets between the Rhine and the harbour **(Fig. 12)**. The EU limit value for NO_2 applicable here was complied with in 2018. The cause analysis for NO_x pollution shows the highest pollution share for the background pollution with about 36 %. Ships on the Rhine reach a share of about 20 %, followed by road traffic (18 %), the ground-level effect of industrial emissions (about 11 %) and port operations (about 5 %).

The traffic measuring station DUMB (NO_2 annual mean in 2018: 42 µg/m³), set up at a traffic hotspot in "Duisburg-Meiderich", shows a clearly different polluter profile for the NO_x pollution **(Fig. 13)**. Here, as expected, road traffic has a dominant polluter share of the NO_x pollution with more than 58 %. The second highest contribution to the present air pollution is made by background pollution with about 24 %. Immissions caused by shipping traffic on the Rhine (approx. 3.5 %) and port operations (1.2 %) play only a minor role.

7. Conclusion

The aim of this part of the CLINSH project was to obtain as accurate as possible a picture of the pollution situation with nitrogen oxides in the large inland ports of Duisburg and

Neuss and to identify the polluters of the air pollution. To achieve this, a very dense measurement network with passive samplers (NO_2 measurement) was set up in both ports. The measurement networks were designed to be considerably denser than is otherwise typical within the official air monitoring measurement network. A total of 47 monitoring sites (19 Neuss; 28 Duisburg) were investigated for CLINSH and, in addition, the results of 8 traffic monitoring sites of the NRW state monitoring network were included in the evaluations.

The additional use of two automatic measuring stations made it possible to record the dynamics of the changes in air pollution with nitrogen oxides with a high temporal resolution. Together with the meteorology also recorded here, it was possible to create a reliable, site-typical data basis for the modelling of the causes of pollution at the CLINSH measuring points presented in this report. For the modelling it has to be kept in mind that the ratio of NO and NO_2 in the emitted exhaust gas in the ambient air does not remain static but can change continuously, influenced by various factors (temperature, ozone content, etc.). For this reason, the NO_2 measurement results are converted into NO_X concentrations (calculated total nitrogen oxides) for the validation of the modelling results.

The modelling carried out for CLINSH has succeeded in describing the pollution situation in the port areas of Duisburg and Neuss over a large area based on the shares of immissions from the individual polluter groups. The validation of the modelling results, using the NO_X concentrations calculated from the measurement results in the study area, shows that a very good agreement was achieved across the area at most of the measurement sites.

At a few measuring sites, the NO_X pollution situation, determined from the NO_2 measurements, could not be completely reproduced by the modelling. This is not unusual due to the size of the area observed and the resulting large number of sources to be considered and potential factors influencing the dispersion modelling (flow obstacles, model resolution, etc.).

As expected, the polluter analysis show a high share of ship immissions at the measuring sites on the Rhine and in the navigable waters of the ports. The same applies at the measuring sites located directly in the ports for the immissions caused by shipping-related port operations. In the navigation channels themselves, high NO_X concentrations are found, where the immission shares of ship emissions strongly dominate, since other ground-level emissions do not have a serious effect there. Already at a distance of 100-150 m from the Rhine, however, significant pollution shares of other emitter groups can be observed.

The measuring stations located in the study area at the traffic hotspots of the state measuring network show a clearly different pollution profile. Here, the effects of NO_X emissions from motorized road traffic dominate with immission shares of mostly more than 50 %. The immission shares of ships are usually below 10 %. This even applies to the traffic measuring sites in Neuss, which are located directly next to the port area. The thesis previously put forward in public discussions, that ship emissions have a dominant share in the pollution situation in the large cities near the Rhine could not be confirmed.

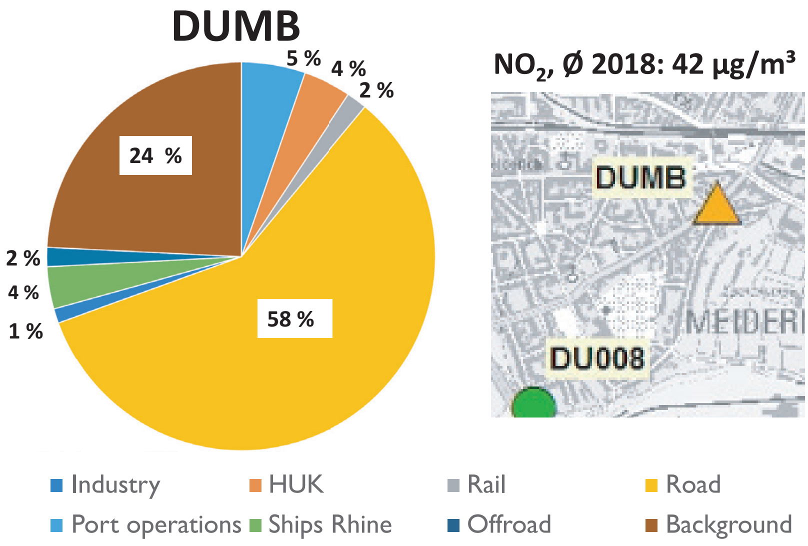


Fig. 13: Causation diagram for NO_X pollution at the NRW traffic monitoring station Duisburg-Meiderich-Bahnhofstraße (DUMB) (residential area) in 2018. The measured NO_2 concentration (annual mean) was 42 µg/m³

Especially in Duisburg, the modelled immission levels of the moving ships on the Rhine overestimate the actual situation at the measuring stations located directly on the Rhine. The modelled NO_X concentrations for the stations along the Rhine are systematically significantly higher than the NO_X values converted from the measured NO_2 concentrations. An open question is whether the NO_2/NO_X conversion approach can be optimized for the composition of ship exhaust near the source and whether the calculation of ship emission factors based on onshore measurements can be further optimized. The measuring sites in the port and settlement areas could generally be described very well with the model results.

8. Outlook

It becomes clear that the investigations carried out by the LANUV as part of the CLINSH project were a very ambitious task.

The port monitoring made it possible to describe the pollution situation and the causes of pollution in the port areas of Duisburg and Neuss. Furthermore, with the data of the automatic measuring stations (dense measuring sequence of five seconds) it was also possible to measure the immission peaks (NO_2, NO) caused by passing ships directly with a suitable wind direction and to assign them to the respective ship causing the immission.

With these results, it was possible to develop, in close cooperation with the University of Bremen, the method described in the LANUV Technical Report 126/CLINSH Report: Harbour Monitoring Part E **[5]** for determining the emission factors of passing ships based on onshore measurements. This allows a more realistic estimation of emissions from passing ships on the Rhine and in ports. The new method allows including the composition (classification) of the real passing fleet as well as its speed profile in the emission estimates.

In addition, the LANUV has developed a method within CLINSH [2] that can also be used to more realistically estimate emissions from ships docked in the port, and which has already been used by other project partners within CLINSH.

The comprehensive (onshore measured) data base as well as the two newly developed methods represent a great gain in knowledge, because the determination of inland waterway emissions in the ports in particular has been difficult so far and required a high degree of simplifications and generalizing assumptions. Moreover, a reliable database on road traffic in the ports and on emissions from port operations has not been existed before the CLINSH project.

The newly developed method still shows potential for optimization in the description of inland waterway vessel emissions from ships sailing on the Rhine. Here, the method described in the LANUV Technical Report 126/CLINSH Report: Harbour Monitoring Part E is to be further developed and improved by further investigations in order to be able to record the inland vessel emissions even more realistically.

The data basis created as part of the CLINSH project and the method developments as a result of the CLINSH project provide the basis for the currently pending update of the emission register "Inland shipping" of the state of NRW. ■

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LANUV-Reports

[1a] "Harbour Monitoring Part A: Air quality on the Rhine and in the inland ports of Duisburg and Neuss/Düsseldorf. Immission-side effect of emissions from shipping and port operations on nitrogen oxide pollution"
[1b] LANUV Fachbericht 115: "Hafenmonitoring: Luftqualität auf dem Rhein und in den Binnenhäfen von Duisburg und Neuss/Düsseldorf – Teil A: Immissionsseitige Effekte der Emissionen aus Schiffs- und Hafenbetrieb auf die Luftbelastung mit Stickoxiden"
[2a] "Harbour Monitoring Part B: Determination of NO_x and particulate matter emissions from inland vessels at berth"
[2b] LANUV Fachbericht 119: "Bestimmung der NO_x- und Feinstaub-emissionen (PM10) von Binnenschiffen am Liegeplatz"
[3a] "Harbour Monitoring Part C: Emission inventories for the ports of Duisburg and Neuss/Düsseldorf"
[3b] LANUV Fachbericht 123: "Hafenmonitoring – Teil B: Emissionsinventare der Hafengebiete Neuss und Duisburg.
[4a] "Harbour Monitoring Part D: Analysis of shipping traffic on the Rhine for the years 2018–2020"
[4b] LANUV Fachbericht 122: "Analyse des Schiffsverkehrs auf dem nordrhein-westfälischen Niederrhein in den Jahren 2018–2020 für das EU-Life-Projekt CLINSH"
[5a] "Harbour Monitoring Part E: Determination of NO_x emission rates of passing vessels from onshore measurements, comparison to on-board observations and application for emission calculations"
[5b] LANUV Fachbericht 126: "Bestimmung von NO_x-Emissionen fahrender Schiffe aus landseitigen Onshore-Messungen und Anwendung zur Emissionsberechnung"
[6a] "Harbour Monitoring Part F: Root cause analysis for airquality measurement results in the inland ports of Neuss and Duisburg.
[6b] LANUV Fachbericht 127: "Immissionsmodellierungen für die Hafengebiete Neuss und Duisburg für das EU-Life-Projekt CLINSH"
[6b] LANUV Fachbericht 127: "Immissionsmodellierungen für die Hafengebiete Neuss und Duisburg für das EU-Life-Projekt CLINSH"

All reports on the LANUV activities in the CLINSH project can be downloaded from the LANUV homepage in German ("Fachberichte") as well as in English ("CLINSH-reports").
www.lanuv.nrw.de/umwelt/luft/eu-life-projekt-clean-inland-shipping

Literature

[7] Janicke Consulting (2019): Dispersion Model LASAT, Version 3.4. Reference Book. Janicke Consulting, Überlingen, Germany.
[8] Schlamberger, C. (2020): Methodenverbesserung zur modelltechnischen NO_2-Bestimmung, Professur für Umweltmeteorologie Christen, Dr. A.; Matzarakis, Prof. Dr. A., Bachelorarbeit von Carina Schlamberger, Freiburg, 2020.

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