Update estimate emissions degassing inland tank vessels

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Preface

In the past years, the subject of degassing has gained increased attention. Representatives from private companies and governments authorities are talking about options directed at substantial reductions of emissions. From the side of industry, VNPI, VNCI and VOTOB take part in these discussions, and also the Port of Rotterdam is strongly involved in this subject.

In order to pave the way for feasible and effective measures, it is clear that there should be an objective and actual insight in the current situation.
We would like to thank the parties mentioned above for the trust they have given to us for carrying out this task.

This project has been guided by a commission chaired by VNPI's Mr. Ed Wijbrands. During the project we worked together in a pleasant and efficient way. We would like to thank him, as well as the other members of the commission Mr. Maurits Prinssen (Port of Rotterdam), Mrs. Leantine Mulder Boeve (VNCI) and Mr. Pehr Teulings (VOTOB) for this cooperation.

The present report makes clear that several aspects relevant for estimating emissions from degassing remain rather uncertain, especially the actual frequencies of degassing and the composition of mixtures. However, the order of magnitude of emissions is clear. The same applies to the development of emissions in the past decade.

As such, we hope that this report provides our principles with the required insights, and as such may serve as a sound basis for future steps to be taken.

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Content

Summary

At the exchange of cargos of petroleum or chemical products, ships can be degassed, resulting in emissions of VOCs (volatile organic compounds). VNPI, VNCI, VOTOB and the Port of Rotterdam have asked CE Delft to investigate the current size of degassing in the Netherlands. Results can serve as a basis for feasible and effective policies.

This investigation can bee seen as an update of a study conducted by CE Delft in 2003 for the year 2002, in which emissions were estimated at 1.81 Kton +/- 55%, using a methodology consistent with the Emission Protocol. Actual emissions from degassing have been investigated for a series of 43 products, using the IVS'90 database of inland shipping transports for the year 2011. According to this database the weights of VOC-products unloaded in the Netherlands in 2011 amount to 17.1 Mton. This is an increase of 75% compared to the quantities unloaded in 2002. The main product-categories are UN 1268 (distillates), UN 1203 (motor gasoline), UN 3295 (HCs n.o.s. (not otherwise specified)) and UN 1863 (jet fuel).

Methodology

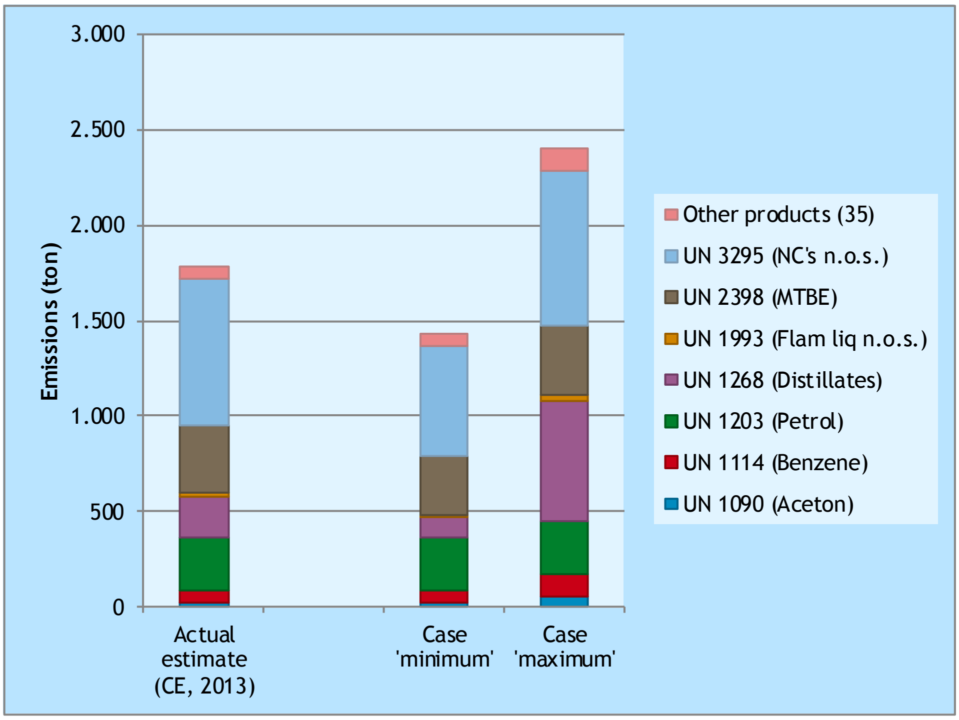
The methodology proposed by the Dutch national Emission protocol is based on three elements: 1. Quantities unloaded (as from the IVS'90 database), 2. Emission factors per product (based on physical properties and correction factors, stated in the Protocol), and 3. Assumptions on the frequency of degassing at a change of load. It should be noted that these assumptions on the frequency of degassing have not been verified in practise. Using the last assumptions, an actual estimate has been made.
In addition to this estimates three other estimates have been made:

- *a theoretical upper limit:* this reflects the total quantity of emissions that would have been released if all ships would have been degassed after unloading;
- *a maximum case:* this reflects the maximum quantity of emissions, within the existing legal framework, and taking into account products that are shipped fully dedicated;
- *a minimum case:* this reflects the minimum quantity of emissions, that would be realised in case vessels would not be degassed in case of a compatible next load.

'Actual' emissions 2011

According to the 'actual' estimate, emission levels in the Netherlands amount to 1.79 Kton. The main products/product-groups emitted are UN 3295 (Hydrocarbons n.o.s.), UN 1268 (distillates), UN 1203 (motor gasoline) and UN 2398 (MTBE). Of these UN 3295 and UN 1268 are 'collected categories'. The estimate has an uncertainty of approximately 55%, therefore emissions will be in the range between 0.8-2.8 Kton. Figure A shows the 'actual' estimate in relation to the 'minimum and maximum case. Emissions are 0.62 Kton lower than the maximum, due to dedication realised in the transports products.
A further significant reduction of 0.36 Kton can be realised if vessel tanks are not degassed in case of a dedicated of compatible next load, using compatibility criteria proposed by the VNPI.

Figure A **'Actual' emissions compared to the 'minimum' and 'maximum' case**



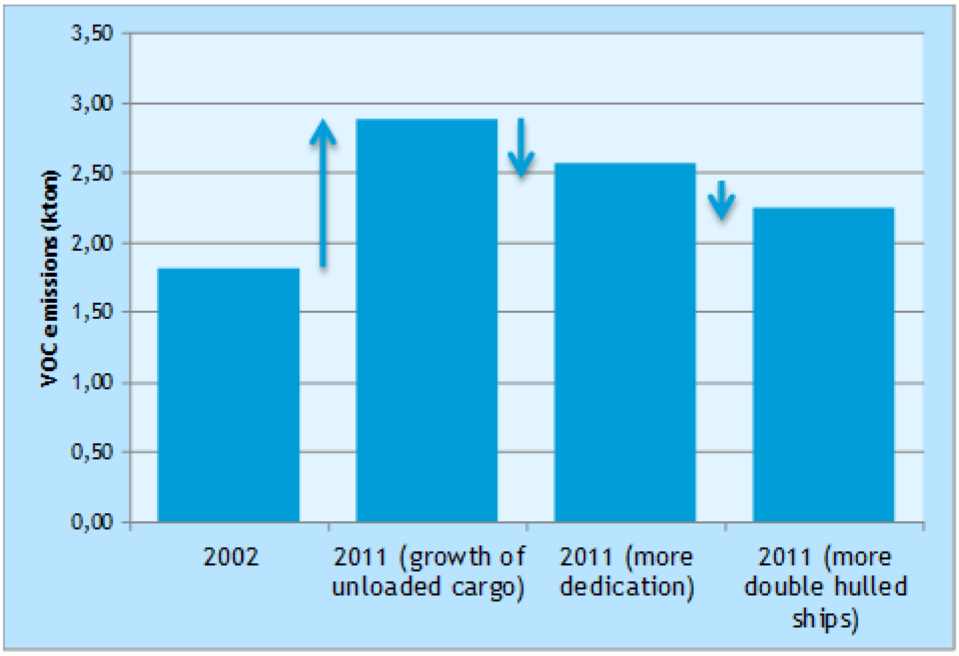
From the IVS'90 database it can be concluded that transports of UN 1280 (Propylene oxide) and UN 1863 (jet fuel) are fully dedicated. For these products no emissions will occur. Also several transports of natural gas distillates, carried out under nitrogen, will be free of emissions.
Also transports of products classified 'T' in the ADN are probably emission-free. Regarding UN 1203 (gasoline) actual emissions of 0.281 Kton have been calculated. According to existing legislation it can be expected that these have not have been emitted into the atmosphere, but treated in vapour treatment units.

Compared to national emissions, the actual emissions from degassing contribute approximately 1.2% to Dutch national emissions. The contribution might be larger for specific components, such as benzene (emissions from degassing of UN 1114 are 59 Kton, or 2.8% of Dutch national emissions, probably also substantial quantities emissions will be emitted from product-mixtures containing benzene).
All estimates have a level of considerable level of uncertainty, in the order of 55%. Actual emissions will be in the range between 0.8-2.8 Ktons. Achieving more accurate estimates of the emissions, will require more insight in the actual incidence of degassing, as well as more insight in the composition of collected product streams.

Development of emissions since 2002

In the 2003 study emissions have been established for seven products. Comparison of emissions of actual emissions with the 2003 results, using identical parameters, indicates that emissions for these seven products have increased with 24%. The increase is due to an 75% increase in products transported. However, emissions have increased less than 75%, due to an increase in dedicated transports (more identical or compatible next loads), and a strong increase in the use of double-hulled ships. These ships have less loadings rests.

Figure B Development of emission from degassing inland vessel tanks 2002-2011



1 Introduction

1.1 Background and purpose

At the exchange of cargos of petroleum or chemical products, ships can be degassed. If degassing occurs in the open air, this can result in emissions of volatile organic compounds into the atmosphere.

Because of the potentially harmful effects of these emissions, in recent years steps have been taken to limit these emissions. The EU Directive 1994/63/EG (European Parliament end Council, 1994) sets restrictions on the degassing of gasoline. Recently, in April 2012, Germany introduced a ban on degassing UN 1268 (distillates) and UN 3475 (ethanol and motor gasoline mixture, with more than 10% ethanol) (Bundesministerium für Verkehr, Bau und Stadsentwicklung, 2011). In this respect, it is a problem that in Germany currently no installations are available for processing the respective vapours. In Belgium all degassing is prohibited, although it is unclear to what extent this is controlled. Furthermore, within the framework of the CDNI[1] and its working group GRTS[2], the emissions of degassing are subject of discussion.

The VNPI, VNCI and VOTOB, representing producers and suppliers of fuels and chemicals, are committed to a safe and responsible transport of their products. It is important for them that measures regarding the reduction of degassing are effective and feasible. This is also of importance for the Port of Rotterdam, regarding its important position in the inland water trade of petroleum and chemical products.
As a basis for effective and feasible policies it is necessary to get a factual and objective picture of the situation around degassing. The four parties mentioned have therefore asked CE Delft to investigate the current size of degassing in the Netherlands.

The emissions from degassing will be compared with national emissions of VOCs from other sources. In 2011 total emissions of VOCs in the Netherlands amounted to 151 Kton (Emissieregistratie, 2013). Also, a comparison will be made with national emissions of benzene, which is relevant part of the VOCs emitted from degassing. National Dutch emissions of benzene amounted to 2.18 Kton in 2011.

This research can be seen as an update of a study conducted by CE Delft in 2003 (CE Delft, 2003). Based on a thorough inventory the volumes of degassing for the base year 2002 emissions were estimated at 1.81 Kton +/- 55%.

This study is now outdated. There have been significant developments in the type of ships used (more ships are double hulled), and the streams of products have changed significantly. Furthermore, the compatibility (loads which are immiscible with each other) is widened. This results in a need for an update for the year 2013 estimate.

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1 The Convention on the collection, delivery and collection of waste in the river Rhine and inland.

2 Steering Committee Gaseous Residues of liquid cargo in inland Tanker Shipping.

A critical factor in the estimate of emissions is the incidence of degassing. The database used did not allow for assessing whether ships actually have been degassed or not, and if degassed, whether this has been at a VTU (vapour treatment unit) or in the open air. In this study assumptions for the incidence of degassing have been based on a methodology proposed by the Emissie-registratie in 2003 (Emissieregistratie, 2003).

Because of differences in the environmental effects of substances emitted, a specification of the types of substances is also needed: CMR (carcinogenic, mutagenic and reproduction-toxic), and odorous substances. From the perspective of the Port of Rotterdam it is also important that the research gives views on the extent of degassing in the Rotterdam region.

Purpose of the study

This study answers the following questions:
- What is the current size of VOC emissions from degassing of inland vessels? What is their share of CMR and odorous substances?
- What is the scope of degassing where the vapour was compatible with the subsequent load?
- What is the extent of other degassing?
- What is the scope of degassing in the Rotterdam Region?
- To what extent do emissions contribute to total national emissions?

Figure 1 Inland vessel transporting a flammable load

1.2 Some backgrounds of degassing

This section gives some technical background on the process of degassing.

In a (ship)tank with a volatile hydrocarbon product, such as gasoline, above the liquid load a vapour will arise. The amount of vapour is determined by the saturated vapour pressure of the product. Hydrocarbons with a vapour pressure greater than 10 Pa at 20˚C, are referred to as volatile organic compounds, or VOCs. When unloading the cargo the maximum amount of vapour in the tank is determined by the saturated vapour pressure and the contents of the tank.

The vapours which remain after unloading, *may* cause the subsequent load to contaminate. Whether this is the case, is determined by the natures of the preceding and subsequent loads. With respect to this, three situations can be distinguished:

- If the ship has *the same subsequent load*, rests of vapours will not result in pollution of the load. From a quality perspective, it is then not necessary to degas. If a vessel always transports the same product it is called 'dedicated transport'.
- If *the subsequent load is compatible*, remains of the first cargo are acceptable for the next cargo. Also in this case it is usually not necessary to degas from a quality perspective. This is particularly the case in a variety of petroleum products. The VNPI has prepared a list of compatible products (VNPI, 2013) (Figure 2).
- If *the subsequent load is not compatible*, remnants of vapours contaminate this cargo. In these cases, ships will be degassed.

Compatibility matrix VNPI

The VNPI has developed a compatibility matrix (Figure 2). This indicates which products are in general compatible with each other. This means that after unloading a product, degassing is not necessary before loading the next compatible load.
Note from VNPI: The matrix shown is only an indication regarding the compatibility between the next and the remains of vapour from the previous cargo (which remain after efficient stripping of the cargo tanks and cargo piping from remaining liquid cargo). Each owner of a cargo determines himself the desired condition of the cargo tank of the tank vessel.

Figure 2 **Compatibility matrix**

Compatibility matrix for clean petroleum products

Previous cargo / new cargo	UN code	Heating Oil dyed	Heating Oil undyed	Diesel dyed	Diesel undyed	Jet A-1	Avgas 100LL	Petroleum	Petroleum (burning kerosene)	Naphtha as Gasoline blending component	FAME
Heating Oil dyed	UN 1202	green	green	green	green	green	red	green	green	green	green
Heating Oil undyed	UN 1202	green	green	green	green	green	red	green	green	green	green
Diesel dyed	UN 1202	green	green	green	green	green	red	green	green	green	green
Diesel undyed	UN 1202	green	green	green	green	green	red	green	green	green	green
Jet A-1	UN 1863	red	red	red	red	green	red	red	red	red	red
Avgas 100LL	UN 1863	red	red	red	red	red	green	red	green	green	red
Petroleum (burning kerosene)	UN 1223	green	green	green	green	green	red	green	green	green	red
Petrol	UN 1203	green	green	green	green	green	red	green	green	green	red
Naphtha as Gasoline blending component	UN 1268	green	green	green	green	green	red	green	green	green	red
FAME	UN 1202	green	green	green	green	green	red	green	green	green	green

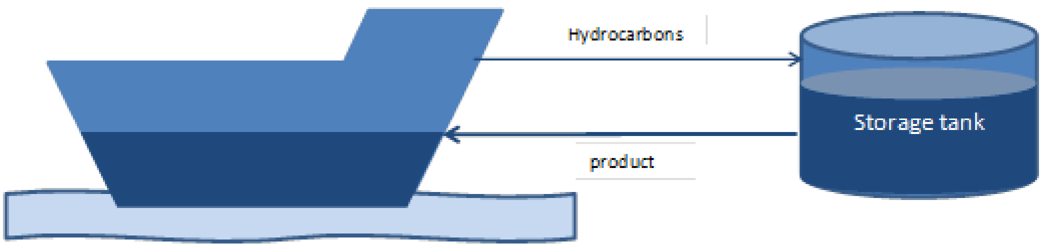
Note: - Discharged according CDNI standard (efficient stripping)
- Loading terminal requirements depending on local VRU properties.

green = recommendable
red = not recommended

Source: VNPI.

This matrix shows in which case a subsequent load of a petroleum products is compatible with the previous load. In these cases it is usually not necessary to release the vapours of the previous cargo. In other cases (marked red), it is necessary to degas.
Degassing can take place via a vapour processing unit or into the environment.
A requirement for using a VTU is that loading terminals/jetties are equipped with VRU connections.
Regarding processing units a distinction can be made between vapour balance and vapour treatment units (DVI's):
- Vapour balance in ship-terminal transfer.
  When a vapour balance system (Figure 3) is at the loading of a ship, the vapour is pushed to a storage tank at the terminal.
- Vapour balance systems in ship-ship transfer.

Figure 3 **Scheme vapour balance. The subsequent load is dedicated or compatible with the vapours of the previous load**



- Vapour treatment installation.
  In a vapour treatment unit the vapours are sent to an installation where they are treated chemically of physically. For this process, various technical concepts exist: adsorption on carbon filters, capture in deep cooling and combustion in a gas engine. This can occur when loading the ship, but also independently. Vapour treatment can take place on shore, but also on the ship. Figure 4 shows a diagram of a VTI during the loading of a ship, Figure 5 is an example of a VTI on the basis of a gas engine.

Figure 4 Scheme vapour treatment. In case of vapour treatment during loading, the subsequent load must be compatible with the previous load

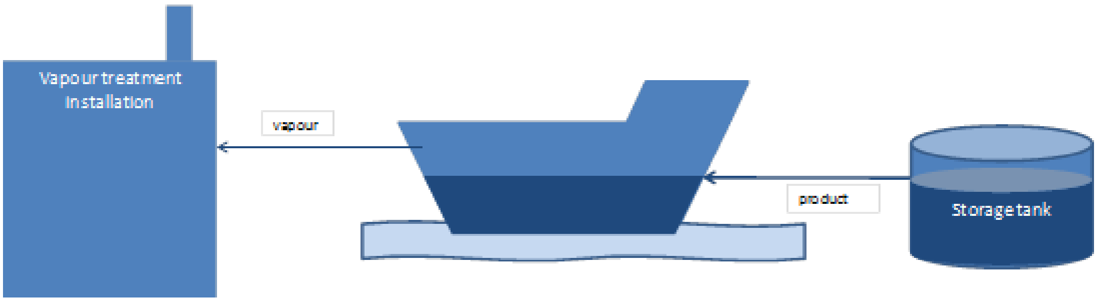
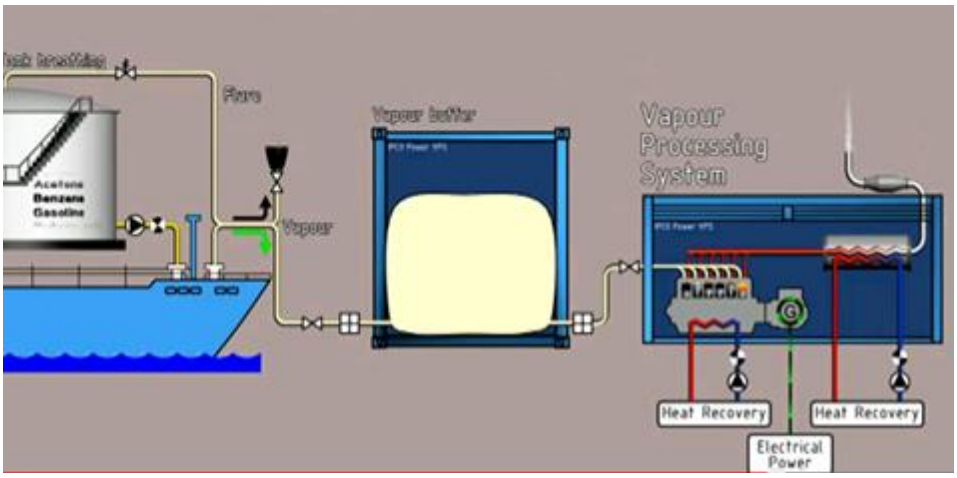


Figure 5 Example of a vapour treatment installation on the basis of a gas engine



Source: http://www.ipcopower.com/vps.html.

- Degassing to the atmosphere.
  In this case, the vapours are discharged into the atmosphere by means of controlled ventilation. The ship is ‘cleaned’ and can transport a wide range of subsequent loads.

Gasfree definition
In the methodology for calculating emissions we assume that the cargo tanks are completely gas free. However, in practice cargo tanks will usually not be degassed until they are completely gas free, but to 10% of the LEL. Therefore a rest of vapour will remain. The rest fraction is limited.
As investigated in the previous study, for UN 1203 (motor gasoline) the quantity between 0 and 10% is less than 1% of the percentage of the quantity of vapour present before venting (CE Delft, 2003; Paragraph 4.4.4). Given the uncertainties in other factors, this can be neglected.

1.3 Investigating emissions degassing: EMS Protocol

Within the framework of the Dutch National Registration of Emission (Emissieregistratie, 2013) protocols have been developed for assessment of emissions of a large variety of sources and substances[3]. One of these protocols is directed at assessing the emissions of VOCs from degassing of ships: the protocol Emissies door Binnenvaart: ontgassing van ladingsdampen naar de lucht. This was originally written by RWS/AVV in October 2003.
This protocol describes an approach for estimating emissions. The approach is consistent with the way CE Delft assessed levels of emissions in the 2003 survey.

The EMS protocol proposes an approach comprised of three steps:
1. Establishing the quantities of VOC-containing products unloaded (the basis for this being the IVS'90 database of RWS/AVV).
2. Emission factor per product. This emission factor relates quantities of products unloaded to corresponding emissions:
   - 2.1 Physical properties of substances (vapour pressure, density).
   - 2.2 Degree of saturation of air in vessel tank.
   - 2.4 Correction factor for temperature.
   - 2.3 Restload after degassing.
3. Assumptions regarding the percentage of cases in which after unloading a tank vessel is being degassed.

Margins of uncertainty
The protocol also elaborates on the uncertainties in the estimation of the emissions. In this respect five levels of uncertainty are being distinguished. Parameter 1 and 2.1 are considered certain. The parameters 2.2 (saturation of air in vessel tank), 2.3 (restload after degassing) and 3 (the percentage of product being degassed) are based on a limited amount of evidence, and therefore are relatively uncertain. The highest factor of uncertainty exists for 'collected groups of products' (UN 1268 (distillates) and UN 3295 (hydrocarbons), not otherwise specified). For these groups of products the actual composition is not well known, resulting in a serious uncertainty regarding the physical properties, especially the vapour pressure.
Overall, the uncertainty of the emission estimates amounts to +/- 50%.

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[3] The Emissieregistratie is coordinated by the Dutch National Institute for Public Health and the Environment (RIVM).

1.4 Emissions in 2002 (CE Delft study)

1.4.1 Methodology

CE Delft investigated the volumes of degassings in 2003 (CE Delft, 2003), in line with the approach proposed by the EMS protocol. The investigation was carried out for the year 2002 using the IVS'90 database of inland shipping transport.

Data-base ship transports

Calculations in the 2003 study have been based on the database IVS'90, which was submitted by the Agency RWS/AVV (Agency Traffic and Transport).
The database provided an overview of all inland shipping transports for the year 2002.
For these it gives: types of products shipped, amounts of products shipped and locations for loading and unloading. This provided a sound basis for calculating emissions.

Selection of products

In the study the seven mostly transported products were selected.
The emissions of these products account for at least 90% of the VOC emissions from degassing.

Table 1 Products investigated in CE Delft's 2003 study

UN code	Product name
1203	Gasoline
1268	Petroleum distillates (combined category)
3295	Hydrocarbons liquid, n.o.s.
1114	Benzene
1230	Methanol
1993	Flammable liquid (combined category)
2398	MTBE

Emission factors

Based on the amounts of products unloaded, emissions have been calculated.
The calculation has been carried out by multiplying quantities of products unloaded with an emission factor based on the saturated vapour pressure.
This is done using the following formula:

$$EF = (EF\ ref \times f(T) \times S + R) \times P\ o$$

In which:

- EF = emission factor (kg emissions/tonne of product)
- EF ref = emission factor based on reference situation saturated vapour
- f (T) = correction for temperature
- S = saturation factor
- R = volume of residual liquid
- P_o = ventilation rate

For this formula that factors **EF ref and f (T)** physical constants for the product.
The **saturation factor S** is the extent to which the tank reaches the saturated vapour pressure at unloading the vapour, and is based on the Handbook Emission Factors/leakage (VROM, 2001 and 2003).
For this, according to the EMS Protocol, a mean value of 0.56 used.

The **volume of residual liquid, R,** is dependent on type of ship.
For single-hull vessels it is larger than for double hull vessels, because in single-hull vessels the tanks are rougher and squarer due to the internal tank construction/frame work, resulting in larger volumes of remaining fluid product. For the remaining residual fluid an average volume of 130 l is assumed (Emissieregistratie,2003) (see also Paragraph 2.3 'remaining products in tanks').

Incidence of degassing

In the IVS'90 database it is not registered whether in case of identical and compatible subsequent loads is degassed or not. In the 2003 study an estimate has been made in accordance with the EMS Protocol. This emission estimate is based on assumptions with regard to the prevention of degassing, which were not validated in practise.
These principles come down to:
- UN 1203 (gasoline) is not degassed in case of an identical subsequent load, and in 20% of the cases with a compatible subsequent load.
- UN 3295 (hydrocarbons n.o.s.), UN 1230 (motor gasoline), UN 1993 (flammable liquid n.o.s.) and UN 2398 (MTBE) with identical subsequent load will be degassed into the atmosphere in 80% of the cases. In case of another next product, it is assumed that these products are degassed in 100% of the cases.
- UN 1114 (benzene) is not degassed in case of an identical subsequent load.

This is summarized in Table 2.

Table 2 Estimates of occurrence of degassing in the EMS Protocol, and used in the 2003 survey

UN code	Identical next load	Compatible next load	Next load not compatible
UN 1203 (Gasoline)	0%	20% (UN 1202 or UN 1268)	100%
UN 1268 (Distillates)	20%	20% (UN 1203)	100%
UN 1114 (Benzene)	0%	N.A.	100%
Other	80%	N.A.	100%

1.4.2 Calculated emissions 2002

Following this approach, the level of emissions of degassing in the Netherlands in 2002 was established at 1.81 Kton. Table 3 gives a breakdown of the emissions to seven products.

Table 3 Emissions from degassing 2002

UN code	Product name	Unloaded weight (Mton)	Emission factor (kg/ton)	Emission in the Netherlands (Kton/year)	Outside the Netherlands (Kton/year)
UN 1203	Gasoline	7.17	0.93	0.7	1.12
UN 1268	Petroleum distillates (combined category)	3.74	0.20	0.15	0.46
UN 3295	Hydrocarbons liquid, n.o.s.	2.45	0.38	0.49	0.87
UN 1114	Benzene	1.27	0.22	0.08	0.19
UN 1230	Methanol	1.27	0.16	0.02	0.18
UN 1993	Flammable liquid (combined category)	0.77	0.24	0.11	0.18
UN 2398	MTBE	0.66	0.65	0.26	0.42
Total		17.33		1.81	2.46

Source: CE Delft, 2003.

The 2003 survey also gives an estimate of the uncertainty. For UN 1203 this is estimated at 27%, for other products at 55%, resulting in an overall level of uncertainty of +/- 50%. Therefore, the emission figure for 2002 is in the range of 0.9–2.7 Kton.

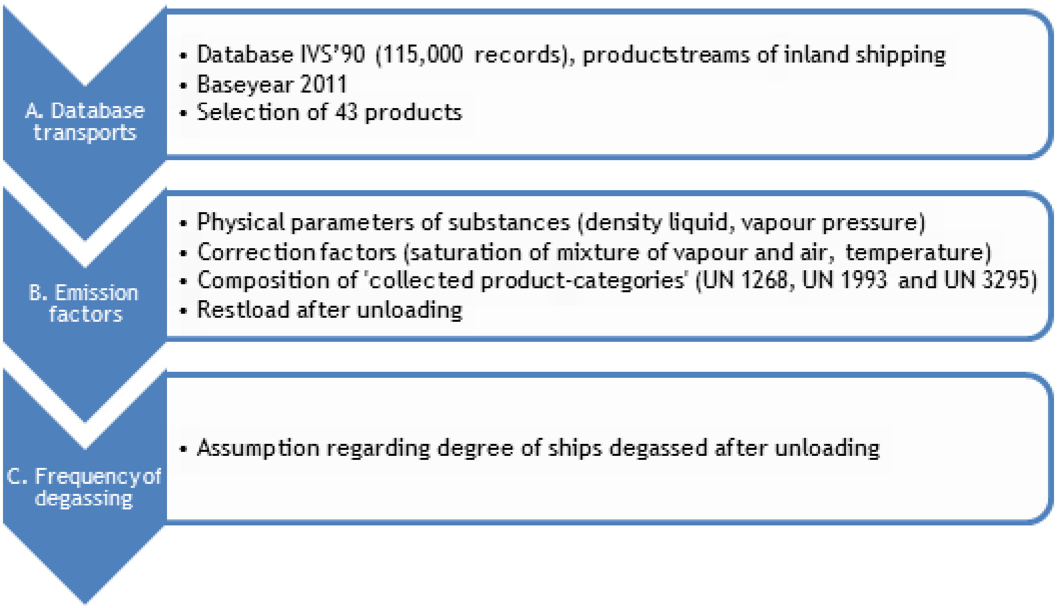
2 Method

2.1 Approach

Emission calculations have been conducted in accordance with the EMS Protocol, and the 2003 CE Delft study. As indicated before, this calculation consists essentially of three factors:
1. Quantities of products shipped (from database file DVS/RWS).
2. Emission factors (Physical factors (density, vapour pressure) and correction factors).
3. Assumptions about the frequency of degassing.

This is illustrated in Figure 6.

Figure 6 Method calculation emissions degassing



Based on these three factors, emissions are calculated with the following formula:

$$[\text{Emission}_{\text{Substance}}\ \text{A (kg)}] = [\text{Weight unloaded}_{\text{A}}\ \text{(ton)}] * [\text{Emission factor}_{\text{A}}\ \text{(kg/ton)}] * [\text{\% of unloading A being degassed (ton/ton)}]$$

2.2 Quantities of products unloaded. Database IVS'90

The basis for the calculations is the database IVS'90, the Information and Monitoring System for Ships (IVS'90). This database is managed by the service WVL of Rijkswaterstaat, and CE Delft was given a copy for the purpose of this investigation. The database contains all transports of chemicals and petroleum products by inland transport. As ship owners are legally obliged to report these transports, it can therefore be assumed that the file is a complete and good reflection of what is being transported.

Technical specifications of the database

– The file is confidential, because the data might be sensitive for competition purposes. Data are only used for this study, and only aggregated figures are reported. There is no direct detectable connection to barge,- names, owners or operators in this report.
– The file contains a total of 115,000 ship transports for the year 2011.
– For each of these transports is registered:
  - the pseudo ship number;
  - the date and time of departure, origin and destination of the transport;
  - the product transported (based on UN product code);
  - the weight of product loaded and unloaded;
  - signs and cones[4].

Analysis of the database revealed that not all of the 115,000 records were always correctly filled out. Some records reflected transports with sea-going vessels. These records were left out of the analysis.

2.2.1 Selected products

The analysis involved 43 products in total. This relates to the 25 products with the highest throughput, to which a series of specific products are added which are relevant from a specific environmental point of view. The latter are provided by the VNCI.
The analysis is limited to products that can be considered volatile hydrocarbons. Hydrocarbons with a low vapour pressure (non-volatile hydrocarbons, such as UN 1202 (gas oil/diesel oil) and UN 9003 (heavy fuel oil) are not included in the calculation of emissions. Inorganic products are also not included. The following list shows which products are included.

Table 4 Products for which degassing emissions have been investigated. The table shows which products were proposed by VNCI, and which were included in the CE Delft 2003 report

UN code	Name	Product list CEFIC	Report CE Delft, 2003
1090	Aceton		
1093	Acrylonitrile, stabilized	✓	
1114	Benzene/pygas/reformate >10% benzene	✓	✓
1120	Butanols	✓	
1145	Cyclohexane		
1170	Ethyl Alcohol	✓	
1173	Ethyl acetate	✓	
1175	Ethyl benzene	✓	
1179	Ethyl butyl ether		
1184	Ethylene dichloride	✓	
1193	Methyl ethyl ketone	✓	
1203	Petrol or gasoline		✓
1206	Heptanes	✓	
1208	Hexanes	✓	
1213	Isobutyl acetate	✓	
1216	Iso octenes		
1219	Isopropyl alcohol	✓	

4 According to the AND, vessels have to carry specific signs or cones during the carriage of specified dangerous substances.

UN code	Name	Product list CEFIC	Report CE Delft, 2003
1220	Isopropyl acetate	✓	
1223	Kerosene		
1230	Methanol	✓	✓
1265	Pentanes (all isomers)	✓	
1268	Petroleum products n.o.s. (Naphtha)	✓	✓
1280	Propylene oxide	✓	
1294	Toluene	✓	
1300	Turpentine substitute	✓	
1301	Vinyl acetate, stabilized	✓	
1307	Xylenes/ethylbenzene (10% or more) mixture	✓	
1547	Aniline	✓	
1662	Nitrobenzene	✓	
1863	Jet fuel	✓	
1918	Isopropylbenzene	✓	
1993	Flammable liquid n.o.s.	✓	✓
2048	Dicyclopentadiene	✓	
2055	Styrene monomer, stabilized	✓	
2312	Phenol, molten	✓	
2398	Methyl-tert-butylether		✓
2491	Ethanolamine	✓	
2789	Acetic acid, glacial or acetic acid solution		
3092	1-Methoxy-2-propanol	✓	
3272	Esters, NOS (Propylene glycol methyl ether acetate)	✓	
3295	Hydrocarbons, liquid n.o.s.	✓	✓
3463	Propionic acid (>90% acid by mass)	✓	
3475	Ethanol and gasoline mixture		

2.3 Emission factors

Calculation of emission factor

The emission factor gives the typical quantity of emissions per quantity of a substance that has been unloaded. The factor is based on saturated vapour pressure, the equilibrium pressure of vapour above a liquid. According to physical principles, the vapour will contain at maximum this quantity. Typical vapour pressures are given for a standard temperature of 20˚C.

Emissions are calculated by multiplying an emission factor based on the saturated vapour pressure with the quantities of cargo unloaded.
As in the 2003 study this is done using the following formula:

$$EF = (EF_{ref} \times f(T) \times S + R) \times P_o$$

In this formula is:
- EF = emission factor (kg emissions/tonne of product)
- EF ref = emission factor based on saturated vapour pressure
- f (T) = correction for temperature
- S = saturation factor
- R = volume of residual liquid
- P_o = ventilation rate

In this formula the factors **EF ref** and **f (T)** represent physical constants for the product.
The **saturation factor S** is the extent to which the tank reaches the saturated vapour pressure at unloading the vapour, and is based on the Handbook Emission Factors/leakage (VROM, 2001 and 2003).
For this, a mean value of 0.56 is observed.
The **volume of residual liquid, R,** is dependent on the type of ship.
For single-hull tankers this volume is greater than for double hull tankers.
In single-hull vessels the tanks rougher, squarer and thicker coated, resulting in more product rests remaining in the tanks. In contrast the newer, double hulled tanks which are smooth and without frames, have lower emissions.[5]

Vapour pressure

Emission factor is based on saturated vapour pressure, the equilibrium pressure of vapour above a liquid. According to physical principles, the vapour will contain at maximum this quantity. Typical vapour pressures are given for a standard temperature of 20˚C. Vapour pressures are derived from the Material Data Safety Sheets of the products selected.

Correction for ambient temperature

On average, temperatures in the Netherlands are lower than 20˚C (9.8˚C long time average (KNMI, 2013)). At a lower temperature, the vapour pressure will be lower, typically 75% of the value for 20˚C (CE Delft, 2003). An exemption is made for gasoline, since the gasoline distributed in winter months has different properties than the product distributed in summer months, with a higher volatility in winter months. Therefore, for gasoline the standard value for 20˚C is maintained.

Saturation factor

Vapours are basically only saturated in the area above the liquid surface and in ‘undisturbed’ situation. After unloading of the cargo, the remaining vapour will not generally reach the saturated pressure in the whole volume of the tanks. This can be expressed by a correction factor, which can only be determined empirically. The factor depends on the material, but also on characteristics of the ship and the tanks and the method of loading and unloading.

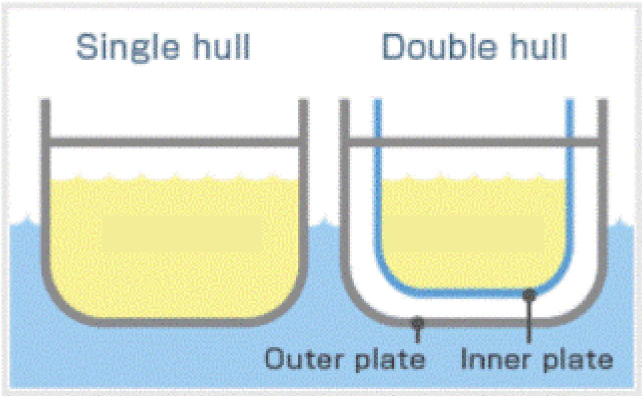
In the Handbook Emission Factors/leakage (VROM, 2001 and 2003) values for the saturation factor is given. These are derived using the AP-42 method of the U.S. Environmental Protection Agency (EPA, 1995) which is also used in the AEA report for the European Commission (AEA, 2001). The Handbook Emission Factors/leakage provides specific saturation factors for tanks at ships that can directly be applied. For a ship with remaining vapours from a previous cargo, with a vapour pressure >10 kPa, a saturation factor of 0.56 is given.
The saturation factor of 0.56 is used for all products.

[5] It should be noted that the formula calculates the volume on the basis of the cargo of the ship and the density. Implicitly, this means that a 100% loading degree is assumed. In practise loading degrees will be lower, in the range of 85%. This could result in net higher emission values.

Remaining product in tanks

Remaining fluids in tanks can evaporate and contribute to emission of vapours. As in the 2003 study we assumed that all remaining fluids eventually evaporate. For the study of 2003, a volume of remaining liquid of 130 litres was assumed. This was composed of: 10 litres per cargo tank; 15 litres per pipelines and 15 litres in the last unloaded tank. Assuming 10 cargo tanks, this amounts up to 130 litres of liquid for the whole ship. With an average load of 2,000 m^3 the residual liquid up to 0.007% of the unloaded cargo (CE Delft, 2003).
Figure 7 illustrates the difference between a single and double hulled tank vessel.

Figure 7 Single hull vs. double hull tank. The picture refers to a sea-going vessel



Source: http://www.marineinsight.com/marine/marine-news/headline/single-hull-vs-double-hull-tankers/.

In double hull vessels less fluids remain. According to the specifications in the ADN at maximum 50 litres (this is based on 7 tanks with 5 litre remaining fluid, and 15 litres remaining in the pipelines) (UN-ECE, 2013a). With an average load of 2,500 m^3, this amounts to 0.0020% of the unloaded cargo.
The ADN sets restrictions for the use of single hulled vessels for the transports of dangerous or flammable products. According to the ADN (UN-ECE, 2013b, Chapter 1.6.7.4.2) the use of double hulled tank vessels is gradually obliged from 31/12/2015 and 31/12/2018, each date referring to a category of products as listed in this chapter. From the EBIS data (European Barge Inspection Scheme) on the numbers of single and double hulled tank vessels on west-European inland waterways can be derived. However, these data are not public, and only accessible for members of the EBIS. Several members of VNPI are also member of EBIS, and therefore the VNPI is familiar to some statistics of the scheme. Furthermore, the VNPI has conducted a survey amongst barge terminals (VNPI, 2013b). According to VNPI it can be concluded from the EBIS-scheme and the survey of barge terminals that per the 1st half of 2013 approx. 95% of the inland tank vessels tonnage was double hulled. By 2011 the share will have been somewhat smaller. For this year CE Delft has estimated the share to be 90%.
Based on a 90% share of double hulled tank vessels for the transports of VOC products, and volumes of remaining products of respectively 130 litres for a single hulled ship en 50 litres for a double hulled ship an average factor of 0.00245% for the remaining fluid can be established. We assume that for all substances the effect of residual substances adds 0.0245 Kton/Mton to the emission factor. This is independent of temperature and saturation level. This estimate is comparable to the one made in the 2003 survey.

Remaining vapours after degassing

In the calculations we propose that the cargo tanks are completely gas free. In practice, this will usually be the case. However, in the petrol distribution directive (EC, 2006), for 'degassed' a limit of 10% LEL is used.
The final amount of vapour, from 10% to 0% LEL will still might be emitted. However, this amount is small, for UN 1203 approximately 0.4% of the saturated vapour pressure[6]. Given all the uncertainties in other factors this can be neglected.

List of emission factors

The resulting emission factors are listed in Annex A. In general emission factors are lower than applied in the 2003 study, due to the lower factor for the remaining liquid product after unloading.

2.4 Assumptions regarding occurrence of degassing

The IVS'90 database on ship transports of dangerous goods does not in all cases allow for assessing if a ship has been degassed after unloading.
Assumptions regarding the occurrence of degassing in case of dedicated/ compatible loadings are based on the from (Emissieregistratie, 2003).
These estimates have also been used in the study (CE Delft, 2003). In three cases assumptions have been adjusted:

- The protocol only provides estimates for eight products. For other products we estimate, in this study, that ships are not degassed in case of an identical next load. An exemption is made for products classified 'T' in the ADN (see Section 4.2).
- For UN 1203 (motor gasoline) the protocol sets the frequency of degassing in case of compatible products at 20%. However, since 2006 it is no longer allowed to degas UN 1203, according to the Petrol Distribution Directive. Therefore in this study we have assumed a 0% of degassing UN 1203 in case of a compatible next load.
- For UN 1268 two more products have been considered compatible: whereas in the 2003 survey only UN 1203 was considered compatible, in this survey also UN 1202 and UN 1223. Also for UN 1223 (kerosene), compatibility was taken into account. This increased compatibility is according to the compatibility matrix of the VNPI.

It is not verified whether these estimates still reflect the situation in 2011. The estimates are not based on actual insights in the usual practise of inland vessels regarding degassing (in which cases ships are usually degassed?, in which cases they are not?). Therefore these estimates of occurrence should be merely considered as a theoretical estimate.

6 The saturated vapour pressure of UN 1203 is 30 kPa, the LEL is 1.2 %. 10% of the LEL equals 0.12 kPa, or 0.4% of the saturated vapour pressure.

Table 5 **Estimates of occurrence of degassing in this survey. The percentages are identical with those proposed by the Emissieregistratie. In case other assumptions have been used, these are shown in *italic***

UN code	Identical next load	Compatible next load	Next load not compatible
UN 1203 (gasoline)	0%	*0%* (UN 1202 or UN 1268)	100%
UN 1268 (distillates)	20%	20% (*UN 1202*, UN 1203, *UN 1268)*	100%
UN 1114 (benzene)	0%	N.A.	100%
UN 1230, UN 1990, UN 2398, UN 3295	80%	N.A.	100%
T-products (ADN): UN 1093, UN 1230, UN 1662, UN 2312, UN 1547	0%	N.A.	0%
Other	0%	N.A.	100%

In addition, in this investigation emissions have been calculated for a minimum and maximum scenario. These reflect the bandwidth between which degassing can occur:

- A maximum scenario. This gives the emissions that at maximum have occurred. In this scenario it is assumed that emissions have taken place at all cases of unloading, except when a ship is fully dedicated.
- A minimum scenario. This gives the emissions that at minimum have occurred. This scenario is based on the assumption that ships have not been degassed in case a following cargo was identical or compatible to the unloaded cargo.

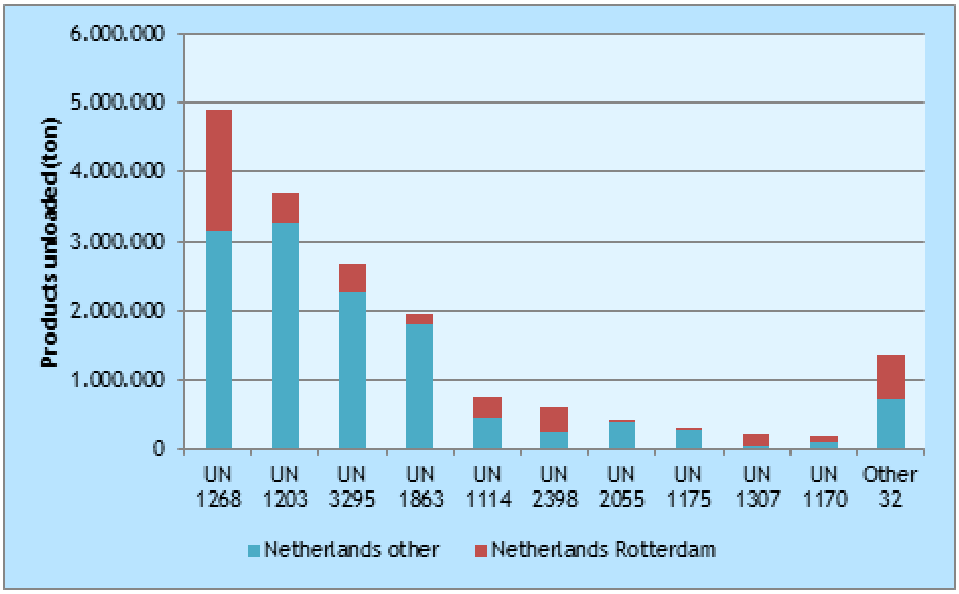
The minimum and maximum scenario together provide a bandwidth.
The factual level of emissions will be somewhere within this bandwidth.

3 Transports 2011

3.1 Products unloaded

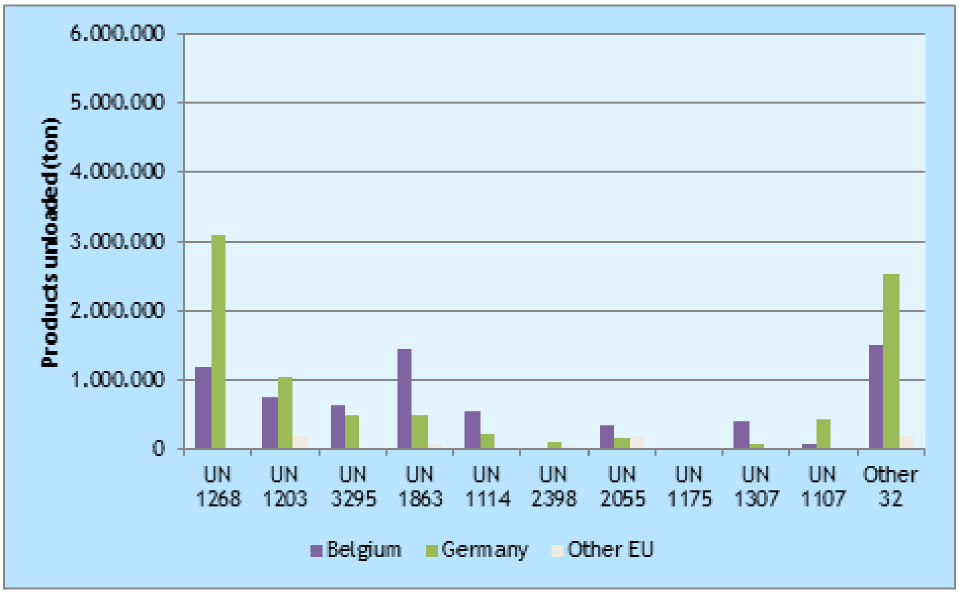
Transported quantities of the 43 products in 2011 are listed in Annex B. Total transport amounted to 33.5 Mton, of which 17.1 Mton was unloaded in the Netherlands and the remaining part, 16.4 Mton, outside the Netherlands. In the Rotterdam region in total 4.4 Mton of product was unloaded.
The 10 products mostly unloaded in the Netherlands are listed in Figure 8. These products will in most cases have been loaded outside the Netherlands, but it is also possible that they arrived from locations in the Netherlands, as the IVS'90 database contains transports of products in the Netherlands. Figure 8 shows the products unloaded outside the Netherlands. These reflect to product-streams that have been loaded in the Netherlands[7].

Figure 8 Top 10 products unloaded in the Netherlands in 2011



7 Occasionally, it might have been possible that f.i. transports from Belgium to Germany or v.v. have crossed the Netherlands.

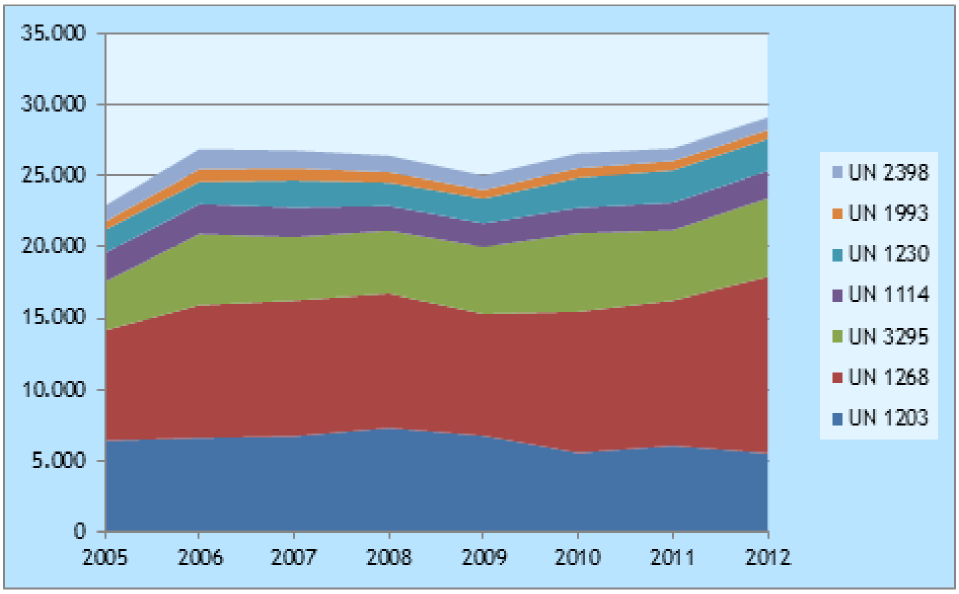
Figure 9 Top 10 products unloaded abroad and transported through the Netherlands in 2011



3.2 Trends of transports

In order to evaluate the representatively of the 2011 data studied, we have compared the transported quantities in 2011 with quantities transported in other years in the period from 2003-2012. For this purpose, RWS/WVL submitted data of the quantities transported of the main seven products at the main infrastructural points in the Dutch waterway network, four sluices and the river Waal. Figure 10 shows the series of transported quantities at these locations. From the figure it can be depicted that volumes in 2011 were in line with those in previous and next years. The volumes of UN 1203 (petrol, motor gasoline) decrease since 2009, whereas the volumes of UN 3295 and UN 1268 have increased since 2005.
Overall it can be concluded that 2011 was a representative year for the evaluation.

Figure 10 Development of transported volumes of VOC products. The figure shows the sums of the volumes that were counted at four sluices and the river Waal



3.3 Products transported mainly dedicated

Several product streams transports can be considered to be 'fully dedicated', meaning that they are always transported by specific ships, that are dedicated to that specific product. In these cases there will not be a requirement for degassing, and these ships will not be vented to open air.

From the data in the database it can be concluded that transports of UN 1280 (Propylene oxide) and UN 1863 (jet fuel) are fully dedicated. In more than 90% of the cases the following load is identical[8]. These two products represent a 13.1% of the total load carried.
Apart from these products also other products are often shipped by the same ships. Table 6 lists products for which the next load was identical in more than 50% of the cases. These products account for 60.0% of the total quantity transported. In most cases these are compatible to the previous load.

8 The remainder will be due to regular control at shipyards or mistakes in the database.

Table 6 Products with identical/compatible next load

UN code	% identical next load	% next load compatible
1280 Propylene oxyde	98%	N.A.
1863 Jet fuel	92%	N.A.
1203 Motor gasoline	56%	34%
1223 Kerosene	28%	53%
1268 Distillates	51%	30%
1230 Methanol	77%	N.A.
2055 Styrene monomere	76%	N.A.
2312 Phenol, molten	76%	N.A.
1216 Iso octenes	74%	N.A.
1184 Ethylene dichloride	72%	N.A.
1114 Benzene	55%	N.A.
1093	52%	N.A.
1662	50%	N.A.

This dedication offers opportunities for avoiding degassing.

4 Emissions from degassing in 2011

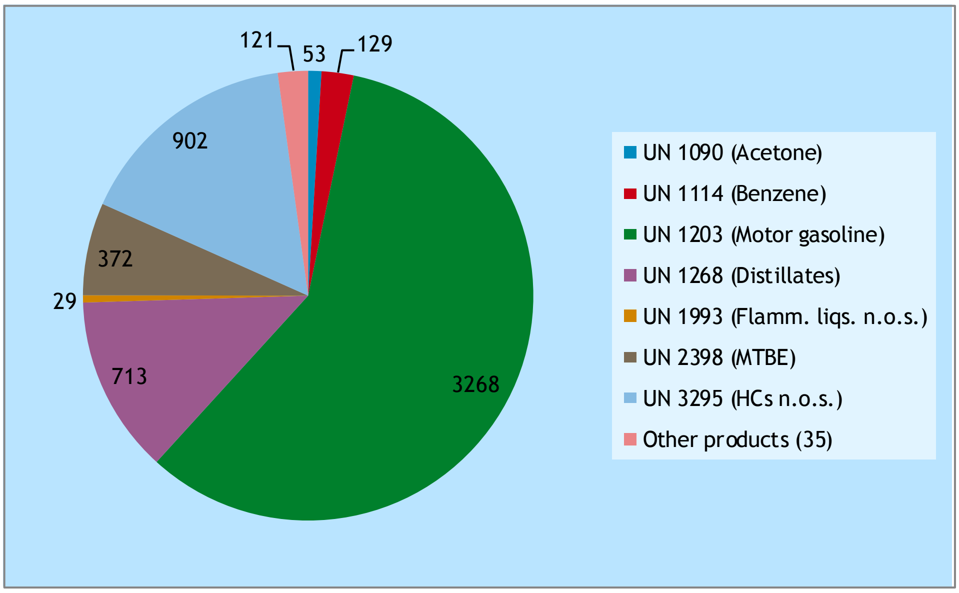
In this section we investigate the levels of emissions from degassing in 2011. As indicated in Chapter 2, it is not certain to which extent ships of which the next load is identical or compatible to the previous one, are in practise degassed. The IVS'90 database does not allow to assess whether in practise ships are degassed in these cases.
For this reason, we have made, additional to an 'actual' estimate (based on the frequencies of degassing of (Emissieregistratie, 2003), calculations for three 'extreme' scenarios regarding the frequency of degassing: a theoretical upper limit, a maximum scenario and a minimum scenario.
Overall emissions have been calculated according to four cases:
- *an actual estimate:* this reflects the quantity of emissions according to the assumptions for degassing as in (Emissieregistratie, 2003) (adjusted for legal developments since 2003);
- *a theoretical upper limit:* this reflects the total quantity of emissions that would have been released if all ships would have been degassed after unloading;
- *a maximum case:* this reflects the maximum quantity of emissions, within the existing legal framework, and taking into account products that are shipped fully dedicated;
- *a minimum case:* this reflects the minimum quantity of emissions, that would be realised in case vessels would not be degassed in case of a compatible next load.

4.1 Theoretical upper limit

This figure gives the technical, theoretical maximum of emissions that would have occurred in case all ships would have been degassed after unloading.
As this is a technical upper limit, this estimate does not take into account legal restrictions for degassing, as in the Petrol Distribution Directive and the products classified 'T' in the ADN[9].
This results in a total theoretical emission of 5.59 Ktons, Figure 11.
The main part of the emissions would be of UN 1203 (motor gasoline).

9 The 'T' classification is further outlined in Paragraph 4.2.

Figure 11 Emissions from degassing in 'theoretical upper limit'



4.2 Maximum case

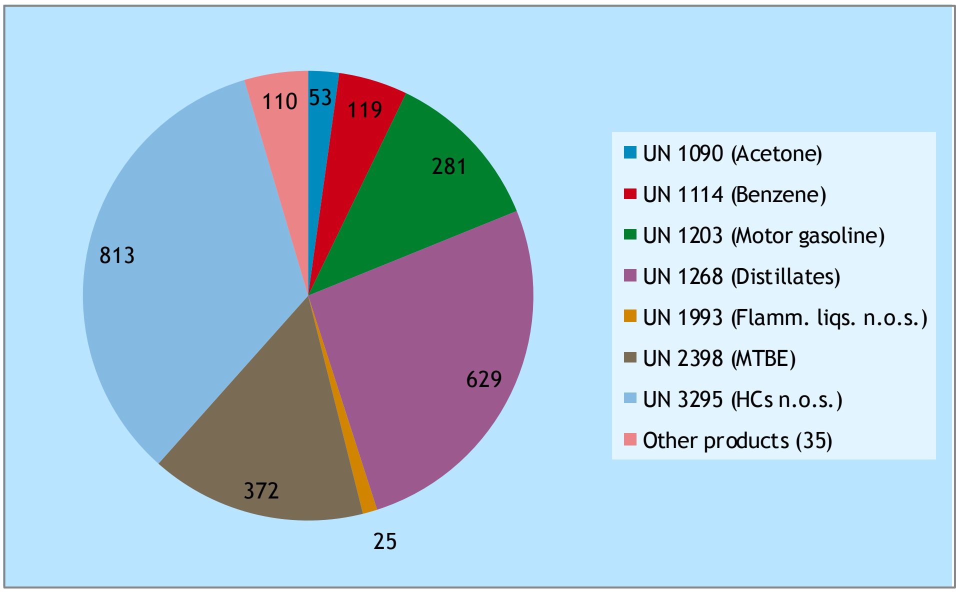
The maximum case estimate is made on the assumption that in all cases ships are degassed after unloading, unless:

- this is prohibited by legal obligations (Petrol Distribution Directive and AND 'T' classified products);
- products are transported in vessels that are fully dedicated for transport of that specific product. As a criterion for dedication we assumed that more than 90% of the cargo during the year transported by a ship is identical.

This maximum scenario results in an emission estimate of 2.40 Kton VOCs. Emissions outside the Netherlands amount to 1.67 Kton, and from the Dutch degassings, 0.70 Kton are emitted in the Rotterdam region. The emissions for the different products considered are listed in Annex C.

Emissions are substantially lower than in the 'theoretical upper limit'. This is due to the fact that in this scenario emissions that are legally prohibited are not emitted. Furthermore, emissions from fully dedicated transports are excluded.
Compared to the theoretical upper limit this results especially in far lower emissions of UN 1203 (motor gasoline), 281 Kton vs. 3,268 Ktons).
The remaining emissions of UN 1203 (motor gasoline, 281 Ktons) results from transports of UN 1203 which are followed by products that are not compatible.

Figure 12 Emissions from degassing according to 'maximum' case



UN 1203 (motor gasoline)

Emissions of UN 1203 are regulated by the EU's Petrol Distribution Directive (EC, 365/24), which has been implemented in Dutch national legislation via the two regulations:

- Regeling Op-, overslag en distributie benzine milieubeheer (Rijksoverheid, 2006a). This regulation is part of the Wet milieubeheer (Environmental Protection Law) and states that a ship may not be loaded with petrol (gasoline) unless a ship is gas free or connected to a vapour balance or treatment system.
- Regeling benzinevervoer in mobiele tanks (Rijksoverheid, 2006b). This regulation is part of the Wet vervoer gevaarlijke stoffen (Law on transport of dangerous substances). According to this Directive UN 1203 should not be degassed. According to this regulation degassing of UN 1203 is not allowed, unless a vessel has carried another product three times (with a loading degree <95%), or is degassed at a vapour treatment installation.

According to the IVS'90 database, transports of UN 1203 are in 92% of the cases followed by identical or compatible following products: in 63% by the identical product, and in 29% by a compatible product (35%). In the remaining 8% of the cases the following product is not compatible.

In this line with this regulation it can be assumed that in the cases of an identical or compatible load, UN 1203 has not been degassed. For the remaining cases, with an incompatible next load, the corresponding emissions amount to 281 tons. According to the legal framework these degassing should have occurred at vapour treatment installations, and have not been emitted to the open air.

Products classified 'T' in the ADN

Several products have a 'T' (toxic) classification in the AND (UN ECE, 2013b). For these, articles 7.2.3.7.0 and 7.2.3.7.1 indicate that they may only be gas freed by competent persons, approved by the competent authority[10]. For the list of products investigated in this study, this applies to four products, UN 1093 (acrylonitrile), UN 1230 (methanol), UN 1662 (nitrobenzene) and UN 2312 (phenol) and UN 1547 (aniline). It can be assumed that these products have not been degassed to the open air. Emissions will have been avoided due to dedicated transports, or in case of a change of loads, by washing or degassing vessels at designated waste/vapour treatment installations.
The total volume of avoided emissions of these five products (compared to the 'theoretical upper limit') is 24 tons.

Products transported fully dedicated

UN 1280 and UN 1863

From the database it can be concluded that the products UN 1280 (propylene oxide) and UN 1863 (jet fuel) are fully transported dedicatedly. For these products no degassing will occur. The emissions avoided, compared to the 'theoretical upper limit' amount to respectively 65 ton and 96 tons.

Transports of UN 1268 under nitrogen

In addition, seven vessels carry condensates of natural gas (UN 1268) from the harbours of Den Helder and Delfzijl to the ARA-area under a nitrogen atmosphere. Also in these transports emissions to the open air will be avoided, thereby avoiding emissions. In comparison to the 'theoretical upper limit' scenarios total emissions avoided by this dedicated transport amount to 48 tons/year.

In the estimates for 2011 these avoided emissions were 48 tons.

Table 7 Emissions in the Netherlands avoided due to dedicated transport (compared to theoretical upper limit)

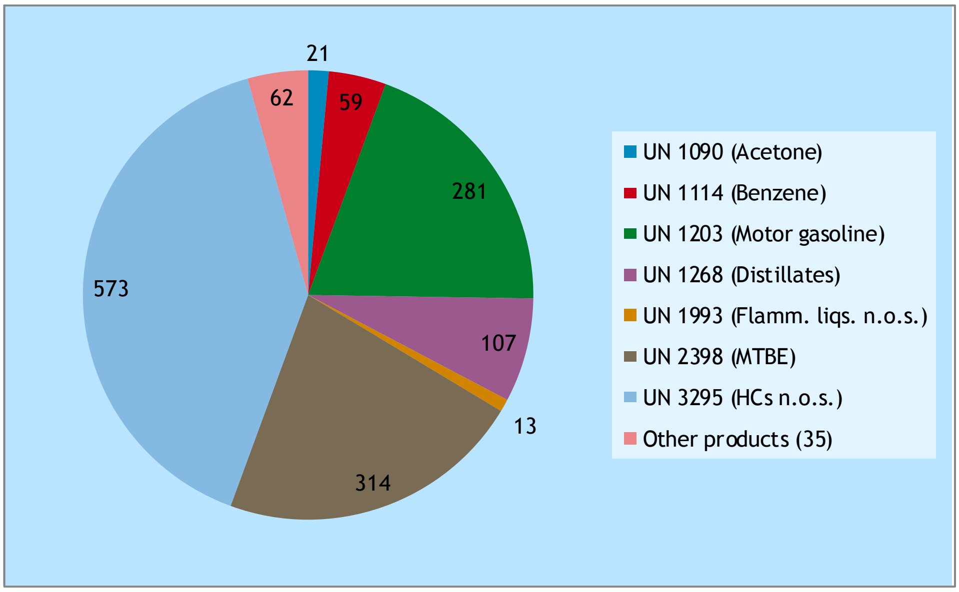
UN code		Avoided emission (compared to theoretical upper limit, ton/year)
1280	Propylene oxide	65
1863	Jet fuel	96
Cargo transported under natural gas		
1268	Distillates (natural gas condensates)	48
Total		209

10 Quote) ADN 7.2.3.7 Degassing of empty cargo tanks.
7.2.3.7.0 Degassing empty or unloaded cargo tanks to the atmosphere is only permitted if it is not prohibited under other international or national regulations.
7.2.3.7.1 Empty or filled cargo tanks which contained in advance hazardous materials of class 2 or 3 in advance with a Classification code containing the letter 'T' in column (3b) of Table C of Chapter 3.2 of Class 6.1 or of Class 8, packing group I, shall only be degassed by competent persons according to subsection 8.2.1.2, or by companies authorized by the competent authority for that purpose. Degassing may only be carried out at locations approved by the competent authority.

4.3 'Minimum' case

Increased dedication might offer opportunities for further reducing the amount of degassing. Based on VNPI's compatibility-matrix (Section 1.2), we have calculated how many emissions can be avoided if ships are not degassed if the following load is identical or compatible. Annex B shows the degree of degassing that follow from this assumption, and Annex C the resulting emissions.
In this case total emissions in the Netherlands amount to 1.43 Kton, of which 0.40 Ktons in Rotterdam. Emissions outside the Netherlands are 1.03 Ktons. The main products emitted are the 'rest category' UN 3295, UN 1203 (gasoline), UN 1268 (distillates) and UN 2398 (MTBE).

Figure 13 **Emissions from degassing in 'minimum' case**



Emissions due to inspections at wharfs

One factor contributing to the emissions in the 'minimum' case are the emissions from periodical surveys visits to wharfs.
According to the Binnenvaartbesluit (decision on inland shipping)[11] inland vessels have to visit a wharf to be inspected. Before such an inspection ships have to be degassed completely (i.e. unto 0% of the LEL). The total amount of emissions stemming from these inspections is calculated at a maximum of 0.18 Kton/year. This amount of emissions can be considered to be difficult to avoid.
The figure of 0.18 Kton/year is based on the following calculation: in 2011 in total 1,493 ships transported volatile organic products, of which 51% is unloaded at in the Netherlands. With an inspection frequency of 1 per 2.5 years, this results in approximately 306 ships being inspected in 2011 in the Netherlands.
The emissions from the degassing of these ships can be estimated from the average emissions that occur in a maximum scenario, in which ships are degassed at all changes of loads. For this scenario it is previously (Section 4.1) calculated that emissions amount to 5.59 Kton. As the total number of unloadings is 9,288 (see Annex A) an average maximum emission of

[11] www.st-ab.nl/wettennr01/1114_001_Binnenvaartbesluit.html.

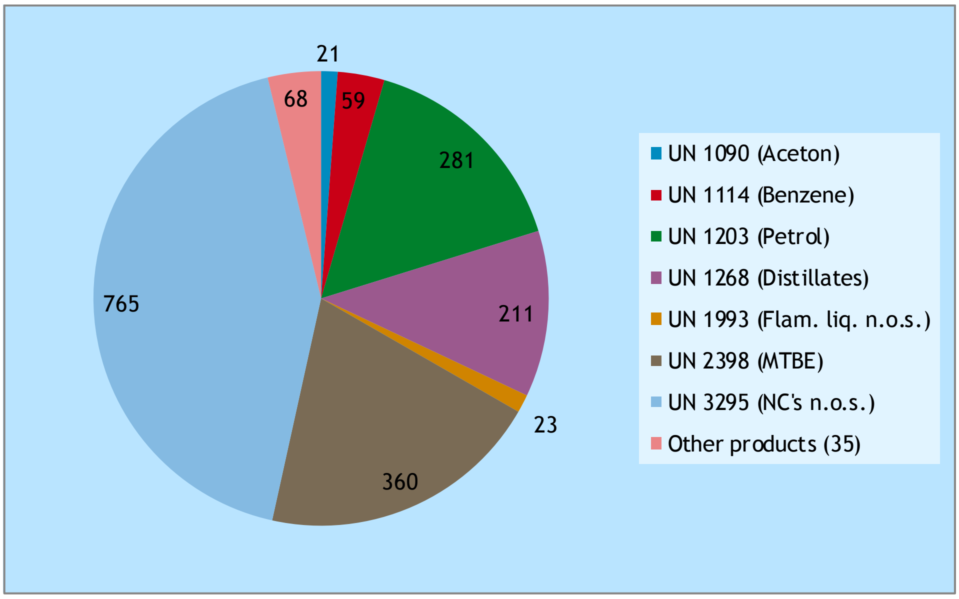
0.58 ton/ship degassed can be derived. This results in a total emission figure for periodical surveys of 0.18 Kton. In practice, when the periodical survey is planned, sometimes the ships will transport products that don't have to be degassed and the emissions will be lower.

4.4 Actual estimate

An actual estimate of the emissions has been established with the adjusted frequencies of degassing from the Protocol of the Emission Registration, as described in Section 2.4. Using these estimates total emissions of 1.79 Kton have been calculated, of which a specification is given in Annex C. The main components of the emissions are shown in Figure 14. It can be concluded that the 'rest category' UN 3295 contributes most to the emissions.
Other important emissions derive from of UN 1203, UN 1268 and UN 2398. The seven products from the 2003 study account for 2.05 Kton, or 97.7%, the other 36 products for the other 2.3%.

Emissions outside the Netherlands amount to 1.21 Kton.

Figure 14 VOC emissions from degassing inland vessels in the Netherlands, 2011 (ton)

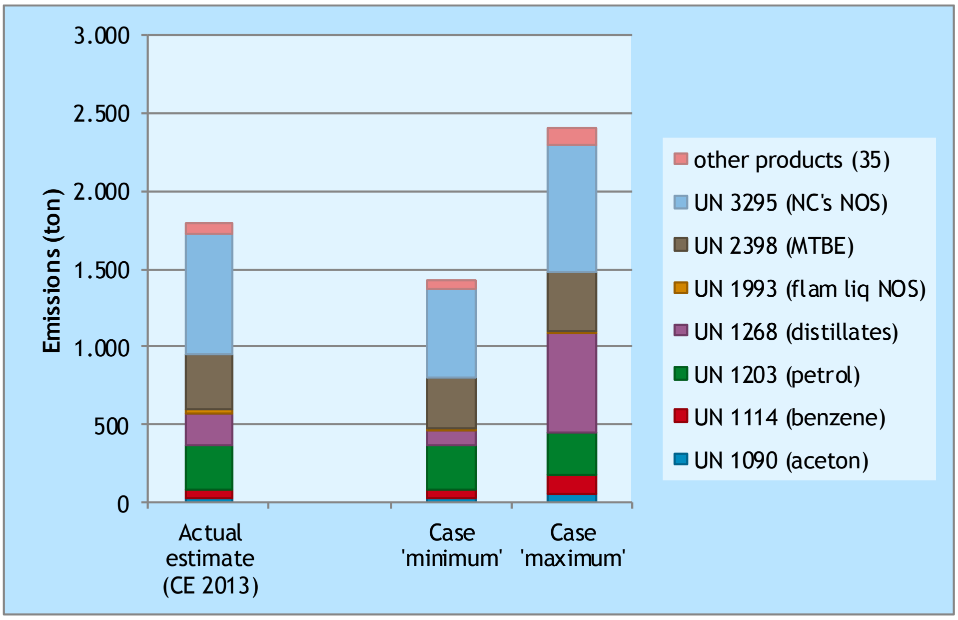


Uncertainty
As in the 2003 estimate, the emission estimates will have a significant degree of uncertainty. According to the Protocol, the estimates have a level of uncertainty of approximately 55%. Therefore, actual emissions will be in the range between 0.8-2.8 Ktons.

Comparison with maximum and minimum case
Figure 15 shows the emissions in the 'actual' estimate, in comparison to the minimum and maximum estimate.
Compared to the maximum scenario actual emissions are 0.61 Kton lower. This is due to avoidance of degassings in cases of identical or compatible next loads. Especially, emissions of UN 1268 are substantially lower than calculated in the maximum scenario (0.26 vs. 0.68 Kton).

In the minimum estimate, emissions are further reduced with 0.36 Kton. This is due to further avoidance of degassing in case of a compatible next load.

Figure 15 Emissions from degassing in the Netherlands according to minimum and maximum estimates

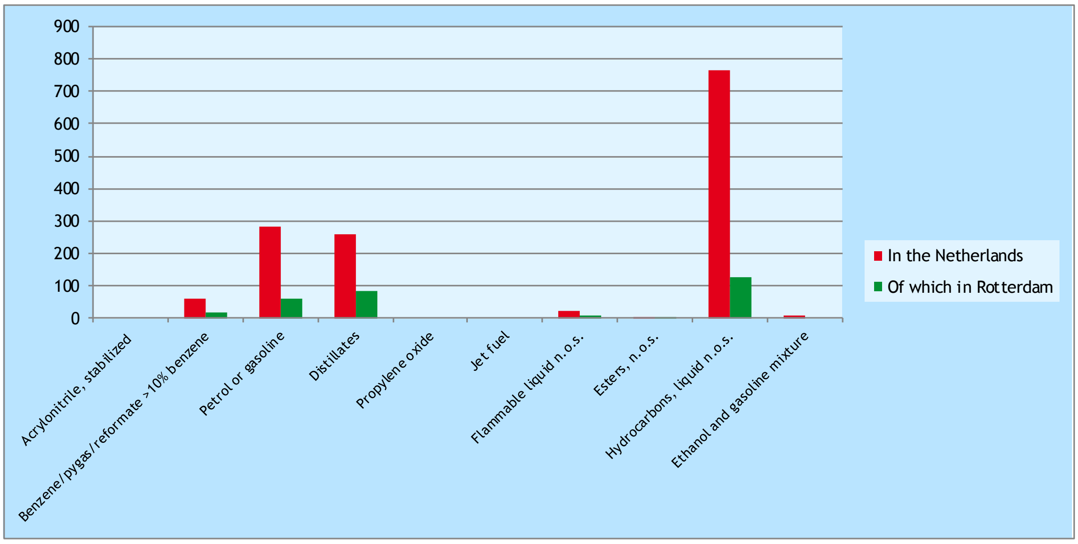


4.5 Emissions of CMR and odorous products

4.5.1 Products classified CMR

From the products evaluated, 10 products are classified 'CMR' (carcinogenic, mutagenic, reproduction-toxic) in the ADN. This includes products which are unloaded in large quantities as UN 1203, UN 1268 and UN 3295. Also the 'T' product UN 1093 is classified CMR. For UN 1280 and UN 1863 transports are fully dedicated.
For the CMR products unloaded transports and actual emissions are indicated in Figure 16. In total emissions amount to 1.39 Ktons, of which 0.29 in the port of Rotterdam. As some large volume products are included in the CMR classification, the figure is not much lower than the 'actual' estimate.

Figure 16 Emissions of CMR products



4.5.2 Odorous products

The Port of Rotterdam's Havenbeheersverordening (Rotterdam Port Management Bye Laws) provides a list of products which potentially cause stench or nuisance (art. 4.1, third item). These are:

– Methylacrylate	UN 1919
– Ethylacrylate	UN 1917
– Iso-butylacrylate	UN 2527
– N-butylacrylate	UN 2348
– Iso-butyraldehyde	UN 2045
– N-butyraldehyde	UN 1129
– Iso-propylamine	UN 1221
– Turpentine	UN 1299
– Propylene oxide	UN 1280

Of these products, only UN 1280 (propylene oxide) was included in this research. In total, 130,384 ton was unloaded in the Netherlands. However, as this product was fully dedicated transported, these have not been degassed.

Two other products have been unloaded in the Netherlands, UN 1919 (methylacrylate) and UN 2348 (n-butylacrylate)[12]. Table 8 shows the quantities unloaded of these products, and the emissions are calculated for these products.

[12] In addition also UN 1917 (ethylacrylate) has been transported (total quantity 4,885 tons), but not unloaded in the Netherlands.

Table 8 **Odorous products: quantities unloaded and calculated emissions**

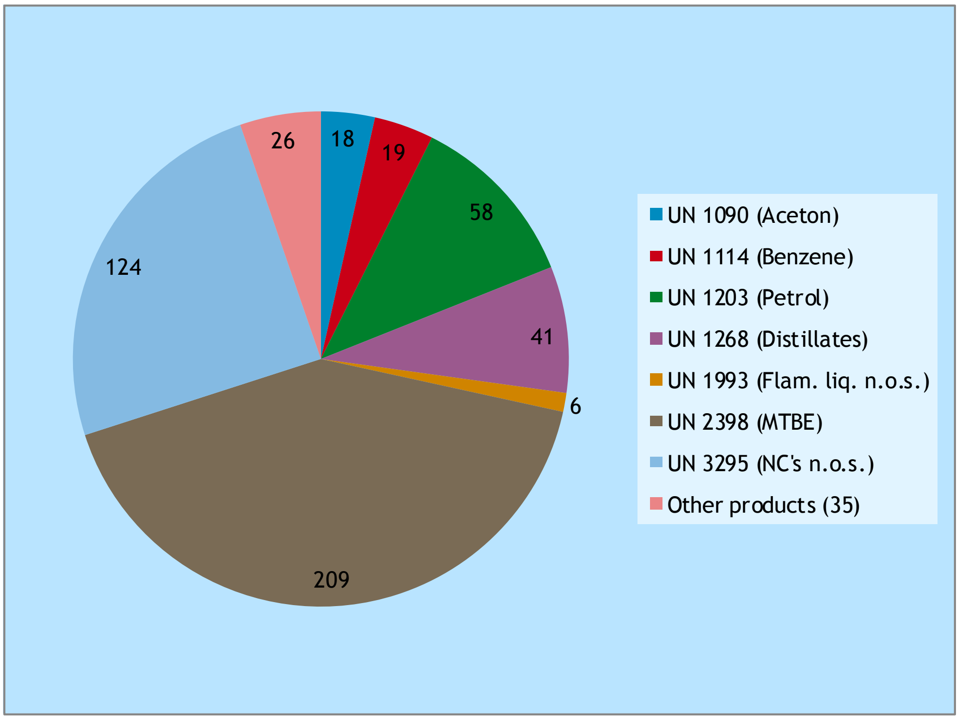
UN code	Unloaded (ton)
	Total
1280 (propylene oxide)	130,384
1919(methylacrylate)	7,496
2348 (n-butylacrylate)	12,978

This results in calculated emissions of 0.66 tons of methylacrylate (all in the Rotterdam port area) and 0.17 tons of n-butylacrylate (of which 0.12 tons in the Rotterdam port area). As according to the Rotterdam Port Management Bye Law, these products may not have been degassed to the atmosphere, these degassings probably have occurred at vapour treatment installations, without emissions to the open air. The same applies for other ports, which have similar regulations as the Rotterdam Bye Law.

4.6 Degassing in the Port of Rotterdam

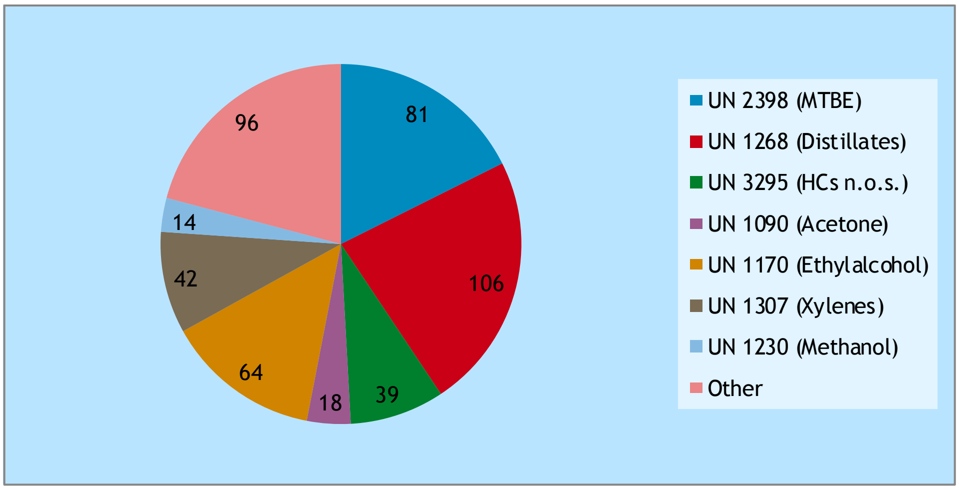
From the Dutch actual emissions, of 1.79 Kton, 0.50 Kton is emitted in the Rotterdam region. Figure 17 shows the distribution of the emissions.

Figure 17 **VOC emissions from degassing inland vessels in Rotterdam, 2011 (ton)**



In the Rotterdam harbours degassing is only allowed at the location Geulhaven, after permission of the Port Authority. The Rotterdam port has submitted data on degassing at this location in 2011 (number of vessels and products degassed). In total 460 ships have been degassed at the Geulhaven. Figure 18 shows the contribution of products degassed.

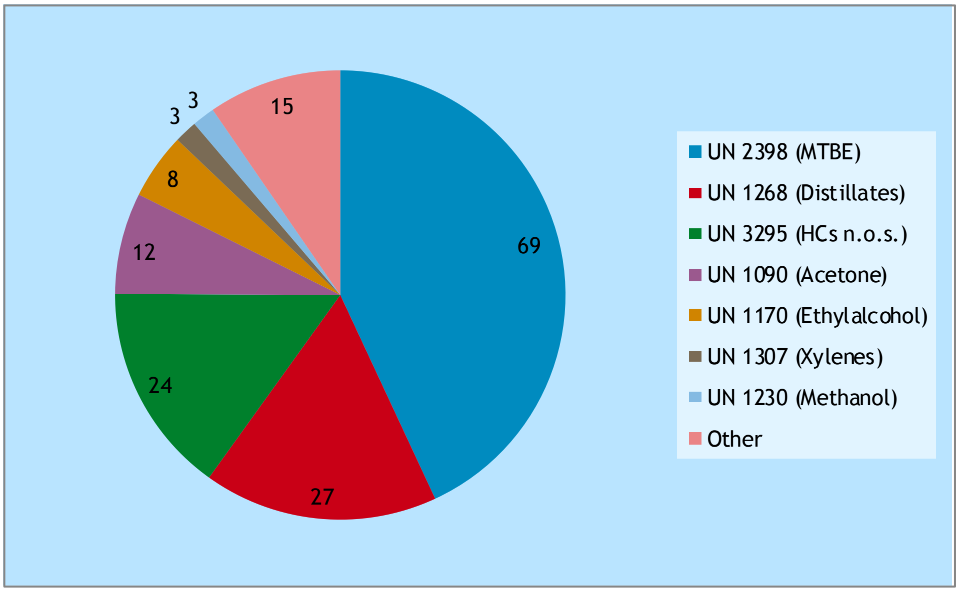
Figure 18 Numbers of degassing at the Rotterdam Geulhaven in 2011 (data from Rotterdam Port Authority)



For these degassings, emissions have been calculated according to the criteria for the actual estimate. The data from the RPA do not specify volumes of vessels or quantities unloaded. Therefore, these have been approached from the IVS'90 database. For each product unloaded the average quantities per ship unloaded in Rotterdam have been established.

The calculation results in the following estimate of emissions at the Geulhaven port (Figure 19). The main products emitted are MTBE, distillates and HCs NOC. In total, the emissions at the Geulhaven amount to 159 ton, or 1/3 of the emissions in the Rotterdam area.

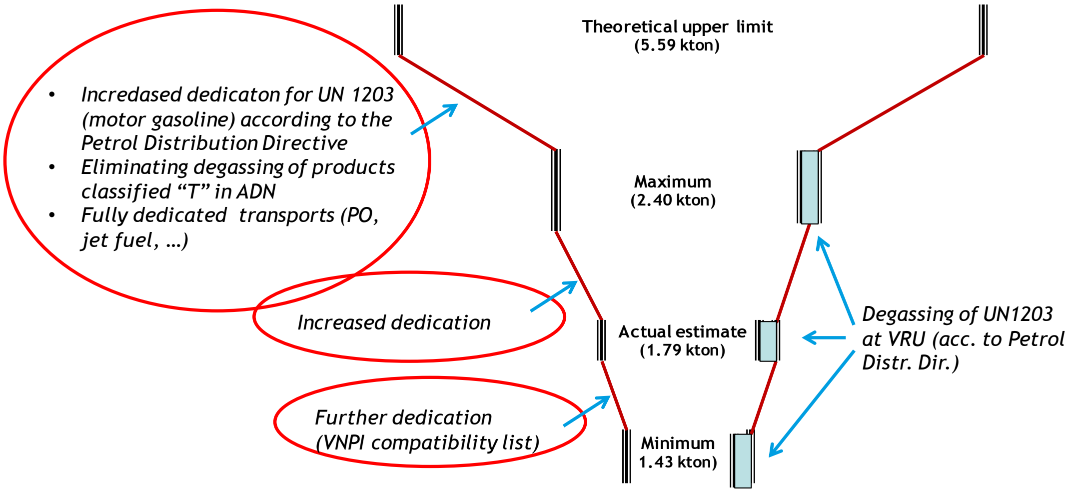
Figure 19 Emissions from degassing at the Geulhaven location in Rotterdam



4.7 Evaluation

Dedication of transports (increased sequences of identical/compatible products carried) can substantially contribute to a reduction of emissions from degassing. This is illustrated by Figure 20. This figure shows the theoretical maximum of emissions, in case all transports would be degassed, a maximum scenario (taking into account that several products are transported 100% dedicated) and the actual emissions. Furthermore, the picture shows the emissions that could have been realised if the compatibility matrix would have been used to a maximum, an no degassing would have occurred in case of an identical/compatible next load.

Figure 20 Impact of dedication on emissions from degassing



Compared to national emissions of VOCs (151 Kton), the contribution of emissions from degassing is 1.2%. For specific substances contribution can be larger, for benzene emissions can contribute to approximately 7% of national emissions[13].

The actual estimate gives an indication of the actual emissions. It is however based on some critical estimates. Critical assumptions are:
- the actual incidence of degassing (in which case a vessel in practise is degassed, in which case not?);
- the composition of mixed product categories UN 1268 and UN 3295.

Improvement of the accuracy of emission estimates requires more insight in these two subjects.

[13] Based on national emissions of 2.18 Kton, emissions from degassing of UN 1114 (benzene, 59 tons), and the benzene content in collected products (UN 1268, UN 3295, with a 10%) Royal Haskoning/DHV, 2013).

5 Comparison with emissions 2002

5.1 Emissions in 2011 compared to emissions in 2002

In CE Delft's 2003 investigation, emissions have been calculated for seven products. Total emissions in the Netherlands were established at a level of 1.81 Kton. The range of uncertainty was estimated at 55%[14].

Using the exact same assumptions and calculation rules for the same seven products, for 2011 the emissions are established at a level of 2.25 Kton, an increase of 0.44 Kton, or 24%. Figure 21 shows the composition of the calculated emissions in 2002 and 2011.

Figure 21 Emissions in 2011 survey compared with 2002. Emissions are calculated with identical calculation rules

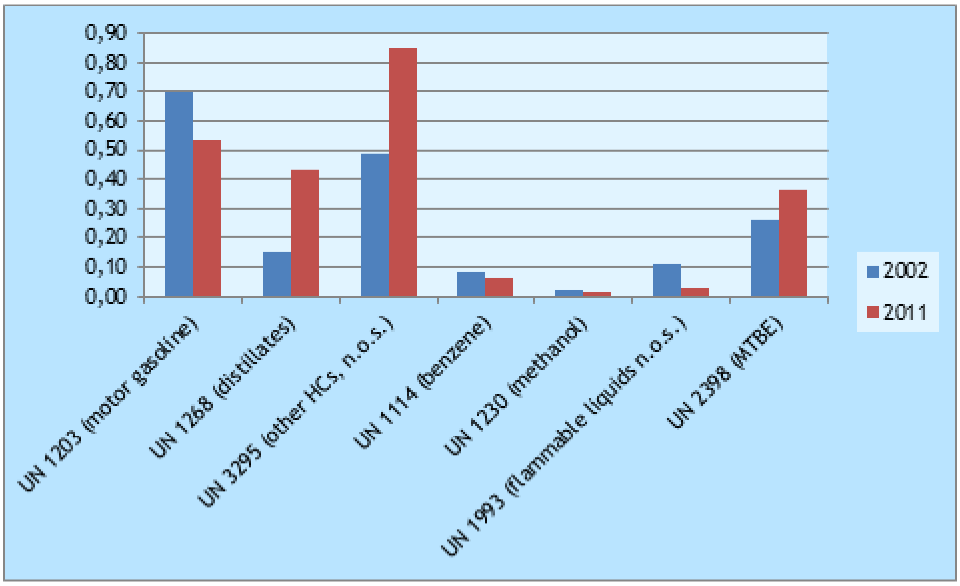


Figure 21 shows that especially emissions have increased of the 'collected categories', UN 1268 (distillates) and UN 3295 (other hydrocarbons, n.o.s.). Together with collected category UN 1993 (flammable liquids n.o.s.), the share of these product categories in the total emissions has increased from 36% in 2002 to 56% in 2013.
According to ADN these mixtures can contain substantial percentages of benzene, the ADN (part 3, chapter 3.2, table C), specifies subcategories with more than 10% benzene. Therefore, with the increase of emissions from 'collected categories', also total emissions of benzene may have increased.

14 For UN 1203, at 27%.

Differences in calculation rules

It should be noted that there is a difference between this figure and the actual estimate (1.79 Kton). This difference is due to different assumptions for the frequency of degassing of UN 1203 and UN 1268 in case of a compatible next load (as outlined in Section 2.4). The main point is that in the 2003 survey it was assumed that in case of a compatible next load of UN 1203 (motor gasoline), in 20% of the cases degassing occurred, whereas in this survey it is assumed that in these cases vessels are not degassed, in accordance with the Petrol Directive.

5.2 Explanation of development of emissions

In the comparison with 2002-figures the increase observed is due to the substantial increase of transported volumes. Transports of these seven products to and inside the Netherlands amounted to 12.96 Mton, compared to 7.40 Mton in 2002, an increase of 75%.
Emissions increased less, due two developments in the transport sector, with an emission reducing effect:

- In 2011 more ships are loaded with an identical or compatible next load. This reduces the need for degassings. In the calculation this affects the percentage of degassing.
- In 2011 more ships are of the double hulled type. These ships have lower rest-loads (typically 50 l in comparison to 130 l in case of single hulled ships, see also Section 2.3). This results in lower emissions from remaining rest products. In the calculation this affects the emission factors.

Overall, these two factors result in a net reduction of emissions with 0.64 Kton, or 22%, compared to a situation without these two developments, as shown in Figure 22. The underlying figures are given in Table 9.

Figure 22 Development of emissions of seven selected products from 2002-2011

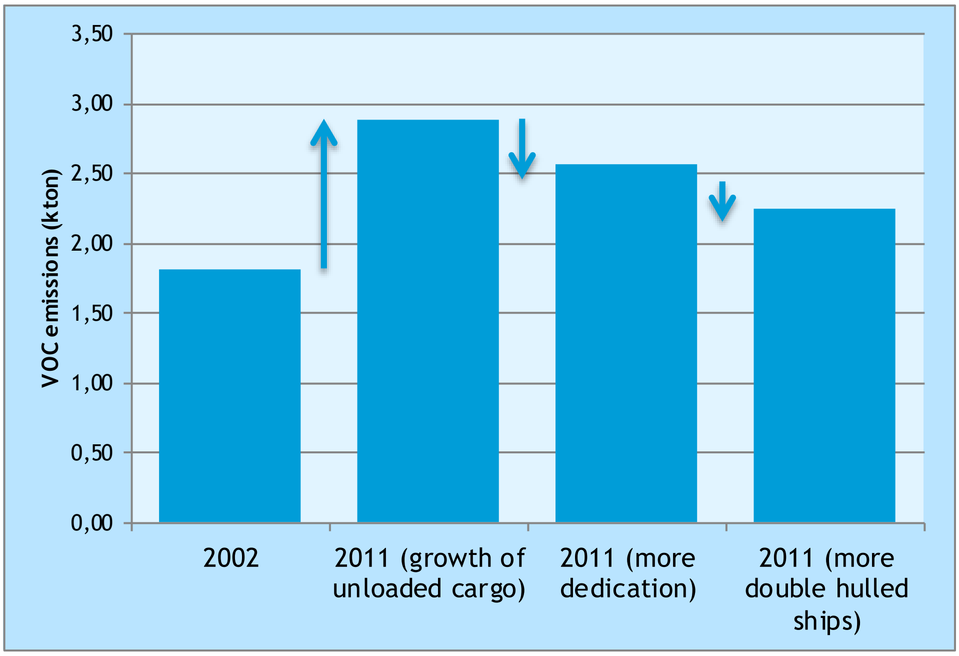


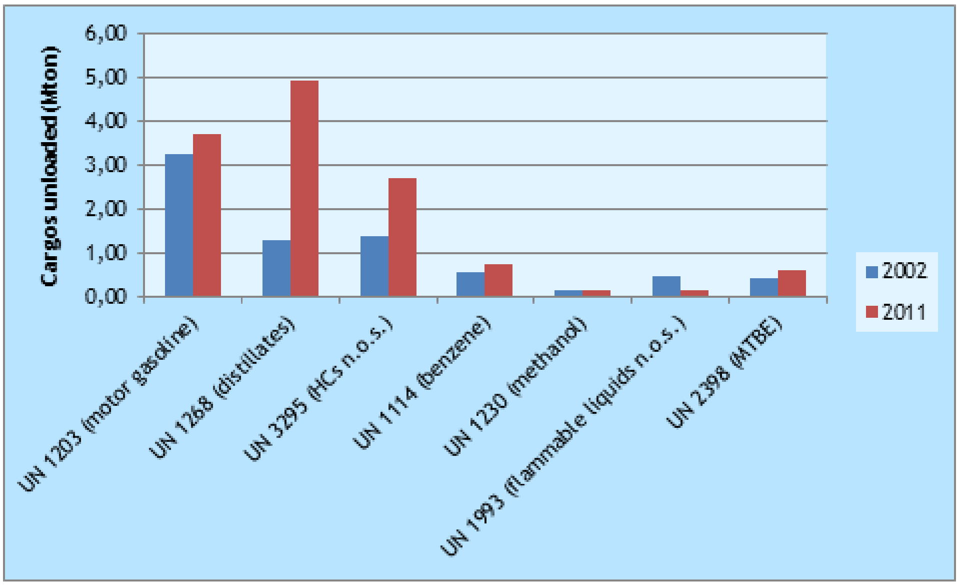
Table 9 **Development of emissions from 2002-2011**

UN code	Emission factor		Degassing		Transported load		VOC emissions			
	Kton/ Mton	Kton/ Mton	%	%	Mton	Mton	Kton	Kton	Kton	Kton
	2002	2011	2002	2011	2002	2011	2002	2011 cargo	2011 dedication	2011 new ships
1203 (Motor gasoline)	0,93	0,88	23	17	3,25	3,71	0,70	0,79	0,58	0,55
1268 (Distillates)	0,20	0,15	60	52	1,30	4,92	0,15	0,59	0,51	0,40
3295 (HCs n.o.s.)	0,38	0,34	93	93	1,38	2,69	0,49	0,95	0,95	0,84
1114 (Benzene)	0,22	0,17	70	45	0,54	0,74	0,08	0,11	0,07	0,06
1230 (Methanol)	0,16	0,11	88	85	0,14	0,14	0,02	0,02	0,02	0,01
1993 (Flammable liquids n.o.s.)	0,24	0,19	96	95	0,48	0,15	0,11	0,03	0,03	0,03
2398 (MTBE)	0,65	0,60	97	97	0,41	0,62	0,26	0,39	0,39	0,36
					7,50	**12,96**	**1,81**	**2,89**	**2,56**	**2,25**

5.2.1 Quantities of products transported

Figure 23 shows the quantities of the seven products transported in 2002 and 2011. The figures represent the weights unloaded in the Netherlands.
The quantities of UN 1268 (distillates) and UN 3295 (Hydrocarbons, N.O.E.) have increased strongly. These 'collective categories' represent 59% of the total weight transported. In total the transported quantity has increased with 75%.
UN 1268 has a relative low emission factor, and a substantial share of the products unloaded is degassed (42%). This results in a increase of emissions from 0.15 to 0.32 Kton. For UN 3295 the emission factor is higher. Combined with a high degree of degassing (93%), this results in a emission of 0.84 Kton. Overall, UN 3295 (HCs n.o.s.), UN 1203 (motor gasoline), UN 1268 (distillates), and UN 2398 (MTBE) account most to the overall transports. Without emission abating measures, this increase in transports would have resulted in an increase of emissions from 1.81–2.89 Kton.

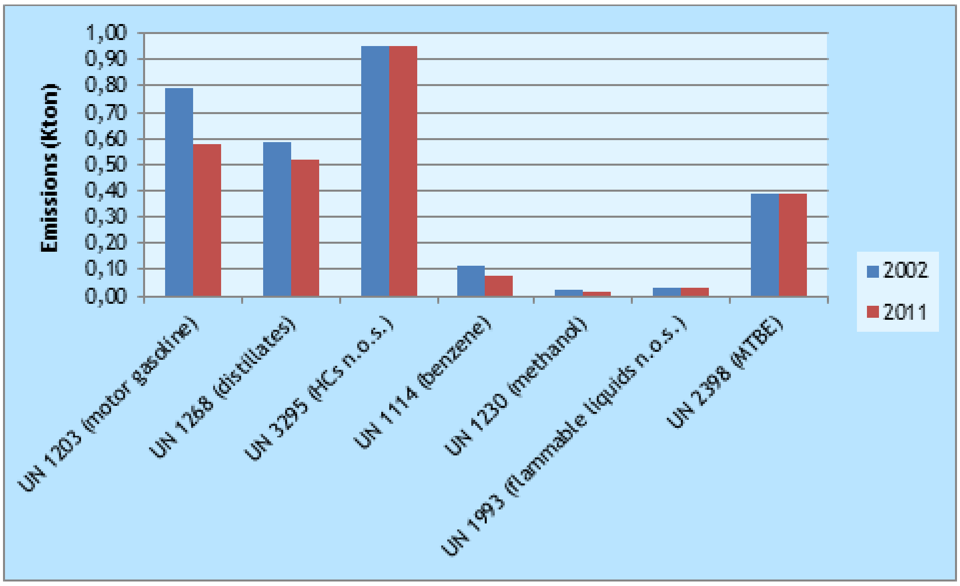
Figure 23 **Products transported in the Netherlands, 2002 and 2011**



5.2.2 Increase of transports of identical or compatible products

Compared to 2002, in 2011 more unloadings are followed by a load that is identical or compatible to the previous one. As a consequence, in less situations degassing is required. Using the assumptions regarding degassing in case of a identical/compatible next load from Section 2.4, effects on the occurrence of degassing have been calculated. This results in reductions of emissions compared to the levels of emissions that would otherwise occur. The increase of dedication has especially an effect on the emissions of UN 1203 (gasoline) and, to a lesser extent, the emissions of UN 1268 (distillates) and UN 1114 (benzene). Overall this increase of dedication results in a reduction of emissions of 11%.

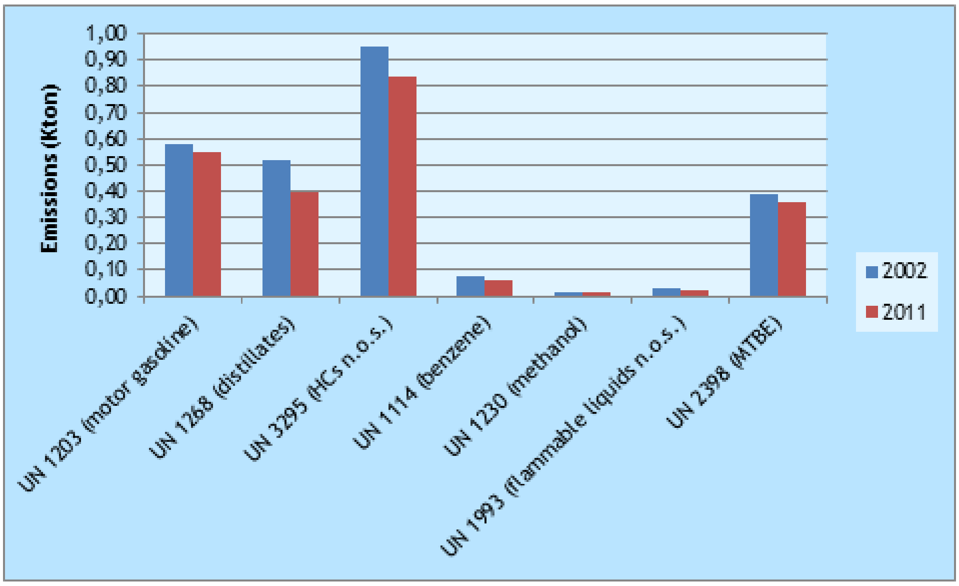
Figure 24 Reduced emissions due to increased dedication



5.2.3 Increase of double hulled ships, and impact on emission factors

As described in Section 2.3, double hulled ships have a lower rest load of products, resulting in a lower emission factor. For the seven products emission factors have reduce typically with 0.4 Kton/Mton product unloaded. This has relatively more effect at products with a low vapour pressure, UN 1268, UN 1230, UN 1114, UN 3295 and UN 1993. Figure 25 shows the effect on the emissions. Overall this effect contributes to a 0.31 Kton, or 12% reduction of emissions compared to a situation in which the fleet would not have been modernized.

Figure 25 Impact of increased use of double hulled ships on emissions



6 Conclusions

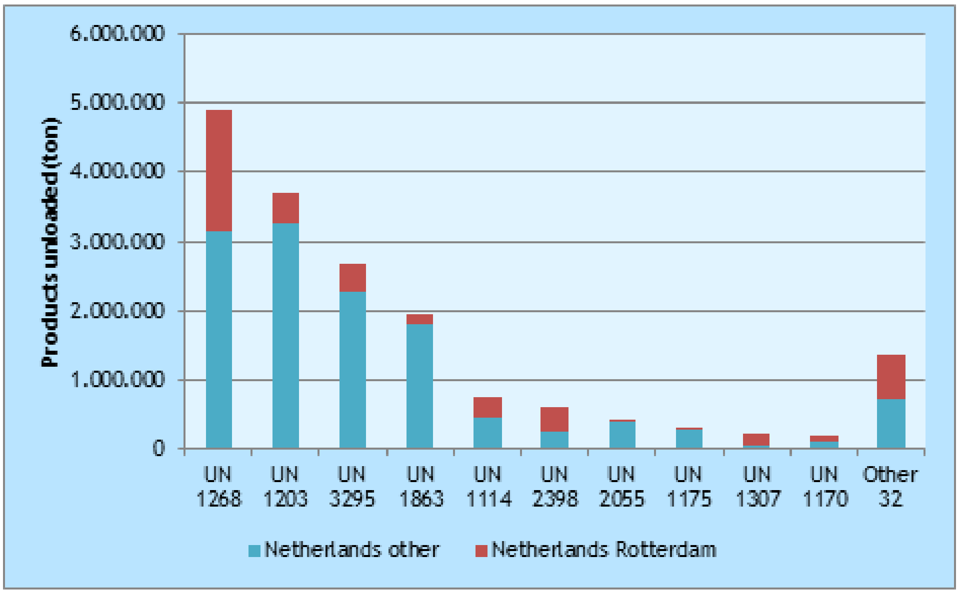
Scope

– In this study actual emissions from degassing have been established for a series of 43 products, using the IVS'90 database of inland shipping transports. Emissions have been analysed and compared with earlier estimates of emissions by CE Delft in 2003 (based on 2002 figures).

Methodology

– According to the IVS'90 database the weights unloaded in the Netherlands amount to 17,1 Mton. The main product categories are UN 1268 (distillates), UN 1203 (motor gasoline), UN 3295 (HCs n.o.s.) and UN 1863 (jet fuel).

Figure 26 Quantities of products unloaded in 2011 in the Netherlands. The figure specifies the quantities unloaded in the Rotterdam port, vs. other ports in the Netherlands (e.g. Amsterdam, Vlissingen and Terneuzen)



– Emissions have been calculated according to the Protocol from the Emissieregistratie, 2003. This calculation is based on three elements:
  - quantities unloaded (as from the IVS'90 database);
  - emission factors per product (based on physical properties and correction factors, stated in the Protocol);
  - assumptions on the shares of products degassed at a change of load (factors from the Protocol have been used[15].

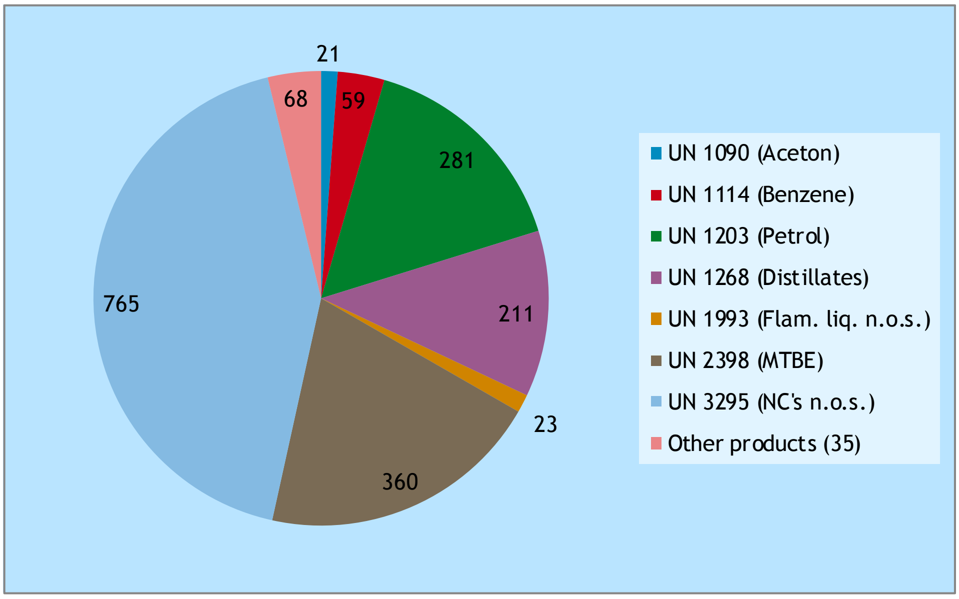
15 UN 1203: if next load is UN 1203: 0%; UN 1202 or UN 1268: 20%, otherwise: 100%. UN 1268: if next load is UN 1268 or UN 1203: 20%, otherwise: 100%. UN 1114: if next load is UN 1114 0%, otherwise 100%. Other products: identical product: 80%, otherwise 100%.

– A critical factor in this calculation is the estimate regarding the occurrence of degassing. From the IVS'90 database it cannot be concluded in which cases in practise vessels have been degassed, and which cases not. In this study an 'actual' estimate has been made based on the (merely theoretical) factors from the Emissieregistratie Protocol. These have been actualised for developments in the legal framework since 2003 (Petrol Distribution Directive).

– In addition to this 'actual' estimate, three other estimates have been made:
  - *a theoretical upper limit*: this reflects the total quantity of emissions that would have been released if all ships would have been degassed after unloading;
  - *a maximum case*: this reflects the maximum quantity of emissions, within the existing legal framework, and taking into account products that are shipped fully dedicated;
  - *a minimum case*: this reflects the minimum quantity of emissions, that would be realised in case vessels would not be degassed in case of a compatible next load.

Emission estimates

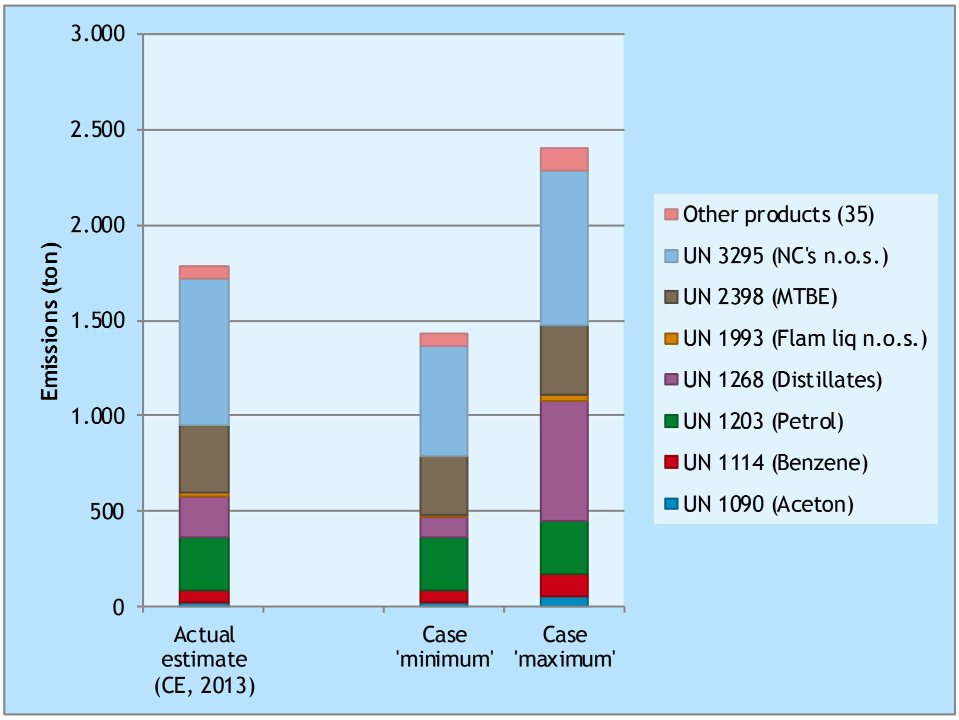
– According to the 'actual' estimate, emission levels in the Netherlands amount to 1.79 Kton. The main products/product-groups emitted are UN 3295, UN 1268, UN 1203 and UN 2398. Of these UN 3295 and UN 1268 are 'collected categories', with differences in chemical composition.



– From the IVS'90 database it appears clear that transports of UN 1280 (Propylene oxide) and UN 1863 (Jet fuel) are fully dedicated. For these products no emissions will occur. Also several transports of natural gas distillates, carried out under nitrogen, will be free of emissions. In total these three product streams account for an avoided emission of 209 Kton.

– Figure 27 shows the actual emissions, in comparison with the minimum and maximum cases.

Figure 27 'Actual' emissions compared to the 'minimum' and 'maximum' case



– Compared to the maximum scenario, emission reductions have especially been realised for UN 1268. This is related to an increase of dedication for transport.

– An emission reduction of 0.36 Kton (from 1.79 to 1.43 Kton) might be realised by full application of VNPI's compatibility matrix.

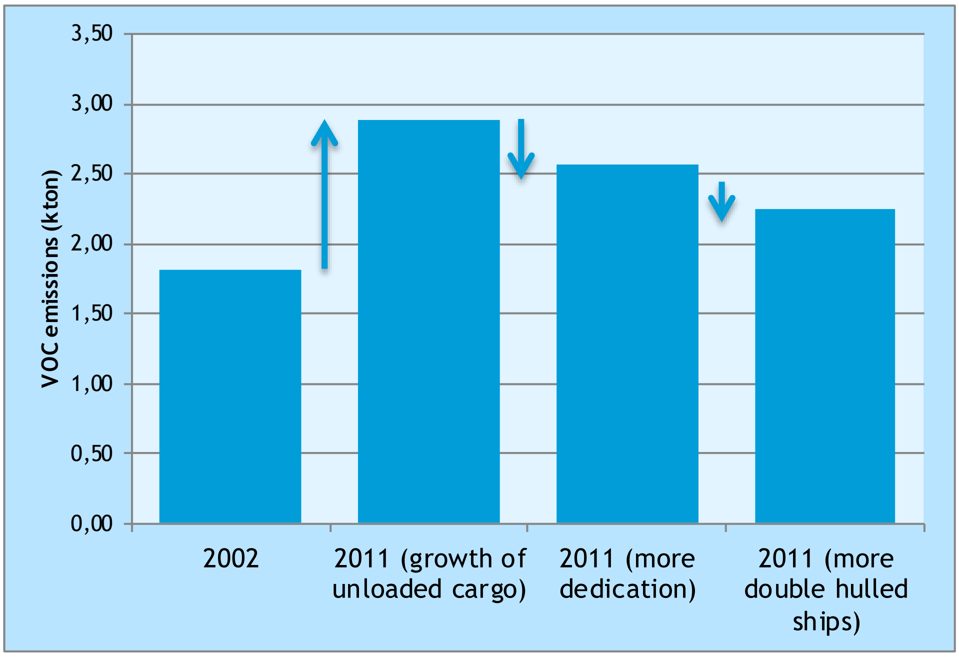
– Compared to national emissions, the actual emissions from degassing contribute approximately 1.2% to Dutch national emissions.
The contribution might be larger for specific components, such as benzene (emissions from degassing of UN 1114 are 59 Kton, or 2.8% of Dutch national emissions, probably also substantial quantities emissions will be emitted from product-mixtures containing benzene).

– All estimates have a level of considerable level of uncertainty, in the order of 55%. Actual emissions will be in the range between 0.8-2.8 Ktons.

– For achieving more accurate estimates of the emissions, it will be required to get more insight in the actual incidence of degassing, as well as more insight in the composition of mixed productstreams, (especially UN 3295 and UN 1268).

Comparison with the 2003 survey

- In the 2003 study emissions have been established for seven products. Comparison of emissions of actual emissions with the 2003 results, applying identical assumptions for the incidences of degassing as used in the 2003 survey, indicates that emissions for these seven products have increased with 20%. The increase is due to an 75% increase in products transported. However, emissions have increased less than this 75% figure, due to an increase in dedicated transports (more identical or compatible next loads), and a strong increase in the use of double hulled ships. These ships have less loadings rests.



References

AVV, 2003
Ernst Bolt
EMS-protocol Emissies door Binnenvaart: Ontgassing van ladingdampen naar lucht
Rotterdam : Adviesdienst Verkeer en Vervoer, (AVV), 2003
http://www.emissieregistratie.nl/ERPUBLIEK/documenten/Lucht%20(Air)/Verkeer%20en%20Vervoer%20(Transport)/EMS-protocollen/EMS%20prot_ontgassen%20ladingdampen%20Binnenvaart.pdf

Bundesministerium Verkehr, Bau und Stadsentwicklung, 2011
Verordnung über die innerstaatliche und grenzüberschreitende Beförderung gefärhlicher Güter auf der Straße, mit Eisenbahnen und auf Binnengewässern (Gefahrgutverordnung Straße, Eisenbahn und Binnenschiffahrt – GGVEB) : Bekanntmachung der Neufassung
In: Bundesgesetzblatt Jahrgang 2011 Teil I Nr. 67, (Bonn 2012) p. 2734-2779
http://www.tes.bam.de/de/regelwerke/gefahrgutvorschriften/docs/GGVSEB_Neufassung_2011_12_16pdf.pdf

CDNI, 2011
Verdrag inzake de verzameling, inname en afgifte van afval in de Rijn- en binnenvaart
Straatsburg : Secretariaat van de Centrale Commissie voor de Rijnvaart (CDNI), 2011

CE Delft, 2003
S.M. (Sander) de Bruyn, M.N. (Maartje) Sevenster, J. (Jessica) van Swigchem, H.J. (Harry) Croezen, K. (Kirsten) van Loo, B.H. (Bart) Boon, F.W. (Folmer) de Haan
Ontgassen van lichters : Een studie naar de mogelijke kosten van maatregelen ter beperking van VOS-emissies in de binnentankvaart
Delft : CE Delft, 2003

Emissieregistratie, 2003
http://www.emissieregistratie.nl/erpubliek/misc/documenten.aspx?ROOT=\Lucht (Air), click to verkeer and then to scheepvaart

European Parliament and Council, 1994
European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations
In: Official Journal of the European Communities, No L 365/24, 31-12-94
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1994:365:0024:0033:EN:PDF

LNE, 2009
Departement Leefmilieu, Natuur en Energie van de Vlaamse overheid (LNE)
31/07/09 Vervoer gevaarlijke goederen binnenwateren
Koninklijk besluit van 31 juli 2009 betreffende het vervoer van gevaarlijke goederen over de binnenwateren
Artikel 7.2.3.7.0 en artikel 7.2.3.7.1
http://navigator.emis.vito.be/milnav-consult/consultatieLink?wettekstId=35192&appLang=nl&wettekstLang=nl

Rijksoverheid, 2006a
Minister van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer
Regeling op-, overslag en distributie benzine milieubeheer
http://wetten.overheid.nl/BWBR0007806/geldigheidsdatum_30-09-2013

Rijksoverheid, 2006b
Minister van Verkeer en Waterstaat
Regeling benzinevervoer in mobiele tanks 2006
http://wetten.overheid.nl/BWBR0018575/geldigheidsdatum_02-12-2011

Rijksoverheid, 2009
Besluit van 18 maart 2009, houdende nadere regels voor de binnenvaart (Binnenvaartbesluit)
In: Staatsblad 2009, no 164
http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/besluiten/2009/06/08/binnenvaartbesluit/binnenvaartbesluit.pdf

UNECE, 2013a
AND 2013 (files)
www.unece.org/trans/danger/publi/adn/adn2011/13files_e.html

UNECE, 2013b
AND 2013 : Part 1, general provisions
b: Chapter 1.6.7.4.2 : Transitional periods applicable to substances, p. 79
http://www.unece.org/fileadmin/DAM/trans/danger/publi/adn/adn2013/English/Part_1.pdf

UNECE, 2013
ADN 2013 : Articles, 7.2.3.7.0 and 7.2.3.7.1
http://www.unece.org/fileadmin/DAM/trans/danger/publi/adn/adn2013/English/Part_7.pdf

VNPI, 2013a
Personal communication VNPI/dhr. E. Wijbrands, 2013

VNPI, 2013b
Personal communication VNPI, compatibility matrix, dhr. E. Wijbrands, 2013

Weekhout, 2012
R. Weekhout (Ministerie van Infrastructuur en Milieu, afd. Binnenvaart en Vaarwegen)
Ontgassing in Nederland, wettelijk kader presentatie September 2012

Annex A Products unloaded (IVS'90 database)

UN code	Name	Transported weight (ton)	Number of shipping movements	Unloaded in Netherlands (ton)	Unloaded outside Netherlands (ton)	Unloaded in Rotterdam (ton)
1268	Petroleum products n.o.s. (Distillates)	9,202,032	4,669	4,918,153	4,283,879	1,754,342
1203	Gasoline	5,723,837	3,377	3,708,394	2,015,443	447,301
3295	Hydrocarbons, liquid n.o.s.	3,823,088	1,950	2,691,357	1,131,730	427,933
1863	Jet fuel	3,975,637	1,574	1,952,092	2,023,545	142,734
1114	Benzene/pygas/reformate >10% benzene	1,502,538	925	738,973	763,564	269,509
2398	Methyl-tert-butylether	791,755	598	615,166	176,588	355,578
2055	Styrene Monomer, stabilized	1,135,801	913	427,893	707,908	41,020
1175	Ethyl benzene	298,796	127	292,511	6,285	2,600
1307	Xylenes/ethylbenzene (10% or more) mixture	717,159	481	234,915	482,244	191,082
1170	Ethyl alcohol	723,563	657	201,170	522,393	81,946
1090	Acetone	321,266	199	180,774	140,492	154,349
1993	Flammable liquid n.o.s.	356,046	408	148,740	207,306	38,363
1230	Methanol	2,014,398	1,518	141,653	1,872,745	85,613
1280	Propylene oxide	406,170	294	130,384	275,786	3,700
1184	Ethylene dichloride	125,736	99	92,445	33,291	2,529
2312	Phenol, molten	121,810	67	89,222	32,588	72,467
2789	Glacid acid	335,353	291	85,013	250,340	26,111
1662	Nitrobenzene	100,780	88	76,342	24,438	60,241
1120	Butanols	138,376	126	64,245	74,131	60,844
1294	Toluene	119,431	100	52,413	67,018	36,499
1300	Turpentine substitute	47,424	36	46,024	1,400	43,476
1918	Isopropylbenzene	322,810	147	38,107	284,703	2,625
1093	Acrylonitrile, stabilized	78,281	67	31,470	46,811	4,165
3272	Esters, n.o.s. (Propylene glycol methyl ether acetate)	24,783	24	21,982	2,801	20,339
1547	Aniline	102,210	76	17,957	84,253	12,821
2209	Formaldehyde solution 32%	53,445	58	14,712	38,733	11,010
2348	Butyl acrylates, stabilized	80,955	102	12,978	67,977	7,480
1301	Vinyl acetate, stabilized	51,353	62	9,835	41,518	9,335
1219	Isopropyl alcohol	20,578	27	8,178	12,400	6,002
1179	Ethyl butyl ether	123,090	105	7,804	115,286	1,975
1216	Iso octenes	138,895	110	7,236	131,659	6,631
1265	Pentanes (all isomers)	8,276	5	4,537	3,739	1,537
2078	Toluene diisocyanate	4,757	6	4,247	510	4,247
1145	Cyclohexane	397,521	351	4,220	393,301	1,320
1208	Hexanes	4,556	6	4,136	420	3,036
3092	1-Methoxy-2-propanol	52,750	67	3,957	48,793	500

UN code	Name	Transported weight (ton)	Number of shipping movements	Unloaded in Netherlands (ton)	Unloaded outside Netherlands (ton)	Unloaded in Rotterdam (ton)
1173	Ethyl acetate	9,454	10	3,490	5,964	1,499
1193	Methyl ethyl ketone	5,600	7	2,950	2,650	2,000
2048	Dicyclopentadiene	7,628	13	1,060	6,568	510
1213	Isobutyl acetate	5,939	6	983	4,956	
3463	Propionic acid with not less than 90% acid by mass	5,064	9	660	4,404	
2491	Ethanolamine	600	1	600		
1206	Heptanes	11,711	11	550	11,161	550
1220	Isopropyl acetate	399	1	399		
1245	Methyl isobutyl ketone	2,860	3	0	2,860	
Total		33,494,510	19,771	17,089,928	16,404,582	4,395,819

A.1 Emission factors

UN code	Name	Density (kg/l)	Vapor pressure (kPa)	Molmass (g/mol)	EF_ref	EF_corr
1090	Aceton	0.7910	24.53	58.08	0.64	0.29
1093	Acrylonitrile, stabilized	0.8100	12.93	53.06	0.33	0.16
1114	Benzene/pygas/reformate >10% benzene	0.8765	10.00	78.11	0.36	0.17
1120	Butanols	0.7750	4.10	74.12	0.17	0.09
1145	Cyclohexane	0.7781	13.07	84.16	0.55	0.26
1170	Ethyl alcohol	0.7890	5.95	46.07	0.14	0.09
1173	Ethyl acetate	0.8970	12.13	88.11	0.47	0.22
1175	Ethyl benzene	0.8665	1.33	106.17	0.07	0.05
1179	Ethyl butyl ether (ethyl-tert-buthylether)	0.7500	6.93	102.17	0.39	0.19
1184	Ethylene dichloride	1.2530	11.60	98.96	0.36	0.18
1193	Methyl ethyl ketone	0.8050	11.87	72.11	0.42	0.20
1203	Petrol or gasoline	0.7500	30.00	104.00	1.43	0.88
1206	Heptanes	0.6795	5.33	100.20	0.33	0.16
1208	Hexanes	0.6548	17.60	86.18	0.87	0.39
1213	Isobutyl acetate	0.8750	2.00	116.16	0.11	0.07
1216	Iso octenes	0.6920	5.50	114.23	0.38	0.18
1219	Isopropyl alcohol	0.7860	5.87	60.10	0.19	0.10
1220	Isopropyl acetate	0.8700	5.73	102.13	0.28	0.14
1223	Kerosene	0.8000	1.00	107.00	0.06	0.05
1230	Methanol	0.7918	13.02	32.04	0.20	0.11
1265	Pentanes (all isomers)	0.6260	57.90	72.15	1.87	0.81
1268	Petroleum products n.o.s.				0.31	0.15
1280	Propylene oxide	0.8300	57.70	58.08	1.13	0.50
1294	Toluene	0.8700	2.80	92.14	0.13	0.08
1300	Turpentine substitute	0.7800	0.50	144.00	0.04	0.04
1301	Vinyl acetate, stabilized	1.0220	12.26	93.19	0.44	0.21
1307	Xylenes/ethylbenzene (10% or more) mixture	0.8640	0.73	106.16	0.04	0.04
1547	Aniline	1.0220	0.04	93.19	0.00	0.03
1662	Nitrobenzene	1.2000	0.02	123.06	0.00	0.02
1863	Jet fuel	0.8000	1.00	107.00	0.06	0.05
1918	Isopropylbenzene	0.8620	1.15	120.20	0.07	0.05

UN code	Name	Density (kg/l)	Vapor pressure (kPa)	Molmass (g/mol)	EF_ref	EF_corr
1993	Flammable liquid n.o.s.				0.40	0.19
2048	Dicyclopentadiene	0.9800	0.27	132.20	0.02	0.03
2055	Styrene monomer, stabilized	0.9090	0.76	104.15	0.04	0.04
2312	Phenol, molten	1.0700	0.05	94.11	0.00	0.03
2398	Methyl-tert-butylether	0.7404	33.20	88.15	1.38	0.60
2491	Ethanolamine	1.1020	0.06	61.08	0.00	0.03
2789	Acetic acid, glacial or acetic acid solution	1.0500	1.52	60.05	0.04	0.04
3092	1-Methoxy-2-propanol	0.9200	1.64	90.10	0.07	0.05
3272	Esters, n.o.s. (Propylene glycol methyl ether acetate)	0.9700	0.49	132.16	0.03	0.04
3295	Hydrocarbons, liquid n.o.s.				0.74	0.34
3463	Propionic acid with no less than 90% acid by mass	0.9900	0.39	74.08	0.01	0.03
3475	Ethanol and gasoline mixture				1.43	0.88

Annex B Percentages of products degassed

UN code	Unloaded in Netherlands	Next load identical	Next load compatible	100% dedicated ships	% degassed
1090	180,774	61%	N.A.	0%	39%
1093	31,470	39%	N.A.	0%	0%
1114	738,973	54%	N.A.	0%	46%
1120	64,245	10%	N.A.	0%	90%
1145	4,220	95%	N.A.	0%	5%
1170	201,170	32%	N.A.	0%	68%
1173	3,490	0%	N.A.	0%	100%
1175	292,511	33%	N.A.	0%	67%
1179	7,804	0%	N.A.	0%	100%
1184	92,445	84%	N.A.	0%	16%
1193	2,950	0%	N.A.	0%	100%
1203	3,708,394	62%	30%	5%	0%
1206	550	0%	N.A.	0%	100%
1208	4,136	0%	N.A.	0%	100%
1213	983	0%	N.A.	0%	100%
1216	7,236	90%	N.A.	90%	10%
1219	8,178	0%	N.A.	0%	100%
1220	399	0%	N.A.	0%	100%
1223	89,908	28%	47%	0%	35%
1230	141,653	76%	N.A.	2%	0%
1265	4,537	0%	N.A.	0%	100%
1268	4,918,153	43%	36%	6%	28%
1280	130,384	96%	N.A.	96%	0%
1294	52,413	26%	N.A.	0%	74%
1300	46,024	15%	N.A.	0%	85%
1301	9,835	42%	N.A.	0%	58%
1307	234,915	30%	N.A.	0%	70%
1547	17,957	27%	N.A.	0%	0%
1662	76,342	63%	N.A.	0%	0%
1863	1,952,092	94%	N.A.	34%	0%
1918	38,107	21%	N.A.	0%	79%
1993	148,740	53%	N.A.	5%	80%
2048	1,060	100%	N.A.	0%	0%
2055	427,893	78%	N.A.	1%	22%
2312	89,222	81%	N.A.	13%	0%
2398	615,166	16%	N.A.	0%	97%
2491	600	0%	N.A.	0%	100%
2789	85,013	50%	N.A.	0%	50%
3092	3,957	0%	N.A.	0%	100%
3272	21,982	0%	N.A.	0%	100%
3295	2,691,357	36%	N.A.	10%	85%
3463	660	0%	N.A.	0%	100%
3475	9,461	30%	N.A.	0%	70%

Annex C Estimates of emissions

UN code	Emissions in Netherlands (ton) Actual estimate (CE Delft, 2013)	Case 'minimum'	Case 'maximum'	Theoretical upper limit
1090	21	21	53	53
1093	0	0	0	0
1114	59	59	119	129
1120	5	5	6	6
1145	0	0	1	1
1170	12	12	17	17
1173	1	1	1	1
1175	11	11	16	16
1179	1	1	1	1
1184	3	3	16	16
1193	1	1	1	1
1203	281	281	281	3,268
1206	0	0	0	0
1208	2	2	2	2
1213	0	0	0	0
1216	0	0	0	1
1219	1	1	1	1
1220	0	0	0	0
1223	2	1	4	4
1230	0	0	0	0
1265	4	4	4	4
1268	211	107	629	713
1280	0	0	0	0
1294	3	3	4	4
1300	2	2	2	2
1301	1	1	2	2
1307	7	7	10	10
1547	0	0	0	0
1662	0	0	0	0
1863	0	0	0	0
1918	2	2	2	2
1993	23	13	25	29
2048	0	0	0	0
2055	4	4	9	17
2312	0	0	0	0
2398	360	314	372	372
2491	0	0	0	0
2789	2	2	3	3
3092	0	0	0	0
3272	1	1	1	1
3295	765	573	813	902
3463	0	0	0	0
3475	6	0	8	8
	1,788	1,430	2,402	5,587

Annex D Transports

	Transport			
UN code	Total number of transports	Transported load (ton)	Of which was unloaded in Netherlands	Of which was unloaded in Rotterdam
1090	199	321,266	180,774	154,349
1093	67	78,281	31,470	4,165
1114	925	1,502,538	738,973	269,509
1120	126	138,376	64,245	60,844
1145	351	397,521	4,220	1,320
1170	657	723,563	201,170	81,946
1173	10	9,454	3,490	1,499
1175	127	298,796	292,511	2,600
1179	105	123,090	7,804	1,975
1184	99	125,736	92,445	2,529
1193	7	5,600	2,950	2,000
1203	3,377	5,723,837	3,708,394	447,301
1206	11	11,711	550	550
1208	6	4,556	4,136	3,036
1213	6	5,939	983	0
1216	110	138,895	7,236	6,631
1219	27	20,578	8,178	6,002
1220	1	399	399	0
1223	80	161,556	89,908	1,008
1230	1,518	2,014,398	141,653	85,613
1265	5	8,276	4,537	1,537
1268	4,669	9,202,032	4,918,153	1,754,342
1280	294	406,170	130,384	3,700
1294	100	119,431	52,413	36,499
1300	36	47,424	46,024	43,476
1301	62	51,353	9,835	9,335
1307	481	717,159	234,915	191,082
1547	76	102,210	17,957	12,821
1662	88	100,780	76,342	60,241
1863	1,574	3,975,637	1,952,092	142,734
1918	147	322,810	38,107	2,625
1993	408	356,046	148,740	38,363
2048	13	7,628	1,060	510
2055	913	1,135,801	427,893	41,020
2312	67	121,810	89,222	72,467
2398	598	791,755	615,166	355,578
2491	1	600	600	0
2789	291	335,353	85,013	26,111
3092	67	52,750	3,957	500
3272	24	24,783	21,982	20,339
3295	1,950	3,823,088	2,691,357	427,933
3463	9	5,064	660	0
3475	5	9,461	9,461	0
Total	19,687	33,52	17,15	4,37