REPORT

Effects of future restrictions in degassing of inland tanker barges

An impact assessment within the framework of the CDNI convention

Client: Ministry of Infrastructure and the Environment

Reference: I&BBE3292R002F01

Revision: 01/Final

Date: 13-6-2016

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Document title:	Effects of future restrictions in degassing of inland tanker barges
Document short title:	Degassing CDNI
Reference:	I&BBE3292R002F01
Revision:	01/Final
Date:	13-6-2016
Project name:	BE3292
Project number:	BE3292
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Date / initials:	13 June 2016
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Date / initials:	13 June 2016

Classification
Project related

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Summary

Reduction of degassing emissions in the CDNI treaty
Inland tanker vessels transport a variety of liquids for industry. Small amounts of liquid and vapour product, remaining in the cargo tanks after unloading, are often released to the atmosphere to avoid contamination. With hazardous cargoes, this so-called degassing of the tanks is harmful for humans and the environment. The governments of the CDNI countries pursuit the incorporation of restrictions to degassing of barges in the CDNI treaty in order to limit harmful emissions to the air.
The CDNI wishes to have a good understanding of the impact on the supply chain of restrictions to degassing. The impact assessment presented in this document provides the needed overview of this impact.

Methodology
The impact on the supply chain was determined on the basis of recent transport data of a selection of seven products. This transport data consists of records from the IVS90 database (2014) completed with other sources on inland tankers transport data from different CDNI-countries. A model was constructed predicting the impacts of market development, the suggested restrictions and market response to such restrictions.

In this impact assessment, we applied a reduction of the number of current degassing due to market optimization mechanisms. This market optimization is very important in the assessment of the impact on the supply chain, but hard to predict. Part of the uncertainty in the expected market response is due to a lack of understanding of compatibility of products. We recommend the development of a better understanding of the market response, including compatibility of products.

Results & discussion
To incorporate degassing restrictions in the CDNI treaty, we recommend a phased introduction. This phasing is based on starting with those products most harmful for humans and the environment and the largest actual transported volumes. We propose the following phasing based on the 7 studied products:

- 2019: UN1114 – UN1267 – UN1268 (> 10% benzene) – UN1863 – UN1993 – UN3295 (> 10% benzene) – UN3475
- 2021: UN1268 (< 10% benzene) – UN3295 (< 10% benzene)

Other products included in the top-25 of most transported products can be included in the second phase in 2021.

We foresee a need for about 1,300 controlled degassings per year in 2019 and 2020 and 2,700 – 3,000 per year in the period 2021 – 2025. This can be realized with 3 installations in 2019 and 2020 and 4 – 5 installations in the period 2021 – 2025. The total cost for the supply chain in these two periods range between 8 and 20 million Euro per year. We believe it will be necessary to have a minimum of 5 installations available from 2019 on to guarantee an acceptable additional sailing time to travel to a nearest degassing installation. The cost-effectiveness of the proposed restrictions ranges from 3 to 25 €/kg avoided VOC emission and 16 to 66 €/kg avoided benzene emission. This is considered proportional. The higher CE of benzene can be accepted based on the carcinogenicity and mutagenicity of benzene.

Sensitivity analysis
There is a significant uncertainty in the input parameters. This propagates to the main outcomes. The largest diversion in impact is seen at the parameter Market Development (partly caused by the largest diversion in input variance), followed by the Average Degassing Time. Four scenarios, based on cohesive estimates for all parameters, show that a great variance is thought to be possible. This is mainly caused by the parameter Market Development.

Samenvatting

Beperken emissies ontgassen in het CDNI-verdrag

De binnentankvaart vervoert een variëteit aan vloeistoffen voor de industrie. Kleine hoeveelheden vloeibaar en dampvormig product, dat achterblijft in ladingtanks na het lossen, worden vaak naar de atmosfeer geëmitteerd om contaminatie te voorkomen. Met schadelijke producten is dit ontgassen van ladingtanks schadelijk voor mens en milieu. De regeringen van de CDNI-landen streven er naar dit te beperken middels een aanpassing in CDNI-verdrag.
De CDNI wenst een goed begrip van de impact van dergelijke beperkingen op de transportketen. De impact assessment die in dit document gepresenteerd wordt, geeft dit inzicht.

Methode

De impact op de transportketen is gebaseerd op recente transportdata en ladingswisselingen van een selectie van zeven producten. Deze transportdata bestaat uit de IVS90 database (2014) aangevuld met andere binnentankvaartgegevens van andere CDNI-landen. Er is een model ontwikkeld dat de impact voorspelt van marktontwikkelingen, de voorgestelde beperkingen en de reactie van de markt hierop.

In deze impact assessment hebben we een reductie van het aantal huidige ontgassingen toegepast als gevolg van optimalisaties in de markt. Deze reductie is erg belangrijk in het vaststellen van de impact, maar ook moeilijk te bepalen. De onzekerheid in de respons van de markt is deels toe te schrijven aan het gebrek aan inzicht in compatibiliteit van producten. We raden aan een beter begrip van de respons van de markt, inclusief compatibiliteit van producten, te ontwikkelen.

Resultaten en discussie

We adviseren een gefaseerde introductie van ontgassingsbeperkingen in het CDNI-verdrag. De fasering is gebaseerd op het starten met de meest schadelijke producten voor mens en milieu en de meest vervoerde producten. We stellen de volgende fasering voor op basis van de zeven producten uit deze impact assessement:

2019: UN1114 – UN1267 – UN1268 (> 10% benzeen) – UN1863 – UN1993 – UN3295 (> 10% benzeen) – UN3475

2021: UN1268 (< 10% benzeen) – UN3295 (< 10% benzeen)

Andere producten van de lijst van 25 meest vervoerde producten kunnen ook in de tweede fase in 2021 worden opgenomen.

We voorzien een vraag naar circa 1.300 gecontroleerde ontgassingen per jaar in 2019 en 2020 en 2.700 – 3.000 per jaar in de periode 2021 – 2025. Dit kan gerealiseerd worden met 3 installaties in 2019 en 2020 en 4 – 5 installaties in de periode 2021 – 2025. De totale kosten voor de vervoersketen in deze twee perioden variëren van 12 tot 25 miljoen Euro per jaar. We achten het nodig om minimaal 5 installaties beschikbaar te hebben vanaf 2019 om acceptabele extra vaartijden te garanderen naar de dichtstbijzijnde ontgassingsinstallatie. De kosteneffectiviteit van de voorgestelde restrictie varieert van 3 – 25 €/kg vermeden VOS-emissie en 16 – 66 €/kg vermeden benzeen-emissie. Dit wordt proportioneel beschouwd. De hogere kosteneffectiviteit van benzeen kan geaccepteerd worden op basis van de carcinogeniteit en mutageniteit van benzeen.

Gevoeligheidsanalyse

De inputparameters hebben een aanzienlijke onzekerheid. Dit propageert naar de uitkomsten. De grootste afwijking geeft de parameter ‘Market Development’ (deels veroorzaakt door de grootste onzekerheid in de input), gevolgd door de gemiddelde ontgassingstijd. Vier scenario’s, gebaseerd op samenhangende waarden voor alle inputparameters, laten een grote mogelijke afwijking in de einduitkomsten zien. Dit wordt vooral veroorzaakt door de parameter ‘Market Development’.

1 Introduction

1.1 Reduction of degassing emissions in the CDNI treaty

Inland tanker vessels transport a variety of liquids for industry. After cargo has been unloaded, small amounts of liquid and vapour product remains in the cargo tanks. This is often released to the atmosphere to avoid contamination of the next cargo. With hazardous cargoes, this so-called degassing of the tanks is harmful for humans and the environment. The governments of the CDNI[1] countries pursuit the incorporation of restrictions to degassing of barges in the CDNI treaty in order to limit harmful emissions to the air.

The CDNI/G[2] working group prepares this gradual incorporation in the CDNI treaty. In addition, a steering committee was established to advice. Members of this Steering committee Gaseous Residues of liquid cargo in inland Tanker Shipping (GRTS) represents a wide number of stakeholders.

The CDNI wishes to have a good understanding of the impact on the supply chain of restrictions to degassing. The impact assessment presented in this document provides the needed overview of this impact.

1.2 Reader's Guide

Report

A background and definition of the issue tackled in this report is given in section 1.3. Section 2 quantifies the issue of degassing in the CDNI countries today. Section 3 gives a suggestion for implementing a degassing restriction, taking into account the size of the impact of such restriction based on the quantification found in section 2. Section 4 monetizes the impact of a degassing restriction as suggested in section 3.

Excel file

This study is largely data-based. However, assumptions are inevitable, and to a great extent determine the outcome of this study. This report is written with a 'fixed set of assumptions' in mind. Since these assumptions are of such great importance they are flexibly integrated in an interactive Microsoft excel file. In this file assumptions can easily be changed, directly impacting the outcomes of number of degassing and costs for the value chain. So though this report is written with seemingly fixed numbers, all assumptions can easily be changed without redoing the study.

1.3 Scope: How do degassing restrictions affect the supply chain?

After a cargo of liquid product has been unloaded, some leftover liquid, gases and vapours remain in tanks and pipes of the tanker barge. Before loading a new product, often these remains need to be purged to avoid contamination. This is called degassing. We distinguish controlled and uncontrolled degassing. Venting the vapour to the atmosphere, uncontrolled degassing, results in undesired emissions to the environment. In order to limit harm to man and environment, controlled degassing is preferred. In controlled degassing, the vapours and gases are sucked from the tanks and treated (see Figure 1-1). Different treatment systems can be used, resulting in different emissions, energy consumption and residual waste/products.

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[1] *CDNI treaty: Convention on the collection, deposit and reception of waste produced during navigation on the Rhine and inland waterways*

[2] *CDNI/G: Group of national experts ad hoc*

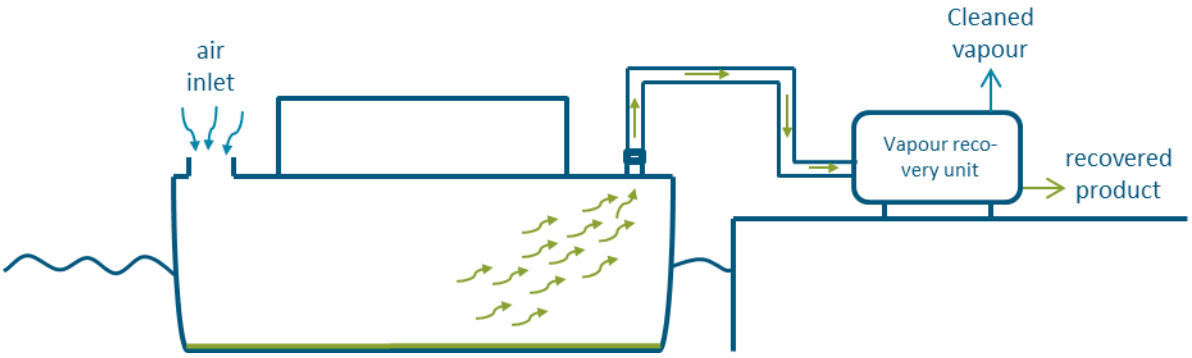

Figure 1-1: Schematic of controlled degassing

The impact assessment results in a good understanding of the material and financial impact for all parties in the inland tanker shipping supply chain of a degassing restriction in the CDNI convention. It might not be possible to restrict degassing of all products at once. For this reason we provide recommendations for a phased implementation of the restriction.

The geographical scope is the area where the CDNI convention is applicable. The impact assessment is based on transport data from several countries. The impact assessment does not answer the question how additional costs should be passed on in the chain.

The impact of degassing restrictions is rather complex. Three major aspects are taken into account in this impact assessment:

- Impact on man and environment;
- Impact on logistics;
- Financial impact.

Impact on Man and Environment
A restriction will reduce emissions from inland waterway shipping to air. Though some may argue that restrictions merely shift impact from one location to another, the international approach of the highly connected CDNI countries makes it likely that environmental impact is actually reduced instead of simply shifted from the CDNI region to other regions. Additional impact is however expected due to increased transport mileage for barges to reach controlled degassing stations. The impact on man and environment is not quantified in this study; this study does not include an environmental impact assessment.

Impact on Logistics
The degassing restrictions discussed in this report are aimed to be implemented by the entire CDNI area. An important aspect is the compatibility of cargoes. 'Compatibility' defines whether a next load B can be loaded after unloading A without the need to degas. Compatibility is defined by the receiving party of load B. Since uncontrolled degassing is free of charge, no cost for degassing is calculated to receiving party B. Party B therefore has no incentive to minimize the list of non-compatible products. It might turn out that once uncontrolled degassing is prohibited, compatibility lists are reviewed and more products become compatible.
A variant of compatible shipping is dedicated shipping. In dedicated shipping, only one single product per barge is transported, so avoiding the need to degas. When uncontrolled degassing is prohibited, we might find more transport to be done in a dedicated form.
This study makes an estimation of the impact on logistics through one of the developed scenarios (Optimal Market Development).

Financial impact
This study aims to make an estimation of the impact in EURO for the supply chain as a whole.
It is noted that controlled degassing installations (designed and dedicated to this purpose) today hardly exist. In the Netherlands, one place for controlled degassing is known (ATM Moerdijk).This entails a large, general gas destruction installation, with an option for barges to apply controlled degassing. This installation is therefore not representative for any new to build dedicated degassing installation. Belgium has two installations in the Port of Antwerp, one active coal and one cryogenic.
With a lack of existing controlled degassing installations (be it on-board, floating or on-shore), no sufficient data on costs is available from practice. The estimation made in this study is based on assumptions.

Important factors that need to be taken into consideration are equipment cost, berth construction costs, operational costs and costs for being idle. Section 4.3 describes in detail the cost per degassing.

This study reviews the supply chain as a whole (section 4.4) and does not make a statement about who is to pay for the defined costs.

2 The scale of the issue: How often do we degas?

To define the scale of the degassing issue, we firstly narrow down the scope of cargoes. Knowing these, an estimate is made for firstly the necessary degassings in the Netherlands today. This figure is then extrapolated to the other CDNI countries. This method is pursued due to the availability of data. Finally we describe two scenarios (*business as usual* and *optimal market development*) to give an estimation of the future need for degassing.

2.1 UN-Numbers in scope

Ultimately, degassing of all products that are harmful when degassed will be forbidden. In this impact assessment, we typify products, based on UN-numbers. As an impact assessment of all products transported in the CDNI countries would require an unnecessarily large amount of resources, this study looks at the most important products based on volume transported and harmfulness only.
To define the scope, we start from the ADN dangerous goods list. Next, we exclude the single UN number that is already prohibited in all CDNI countries: UN1203. Next, we limit to the 25 most transported products[3]. Since volatile products are relevant for emissions to air, only products with a vapour pressure below 10 kPa at 20°C are considered. Next, only acute toxic and products with carcinogenic, reprotoxic or mutagenic (CRM) properties are considered. This results in a list as prepared previously by the GRTS [17]. UN3475 is added to the list because degassing of UN3475 is already restricted in Germany (as is UN1268 and UN 3295 which are included in this impact assessment). Table 2-1 shows this UN number selection.

It should be noted that all products included in this impact assessment are included because they (can) contain significant amounts of benzene, which has CRM properties. Degassing of benzene is already restricted in parts of the Netherlands by Provincial Environmental Act (Dutch: Provinciale Milieuverordening).

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[3] *Selected previously on basis of the Dutch IVS90 database with 2012-data [17,21]*

Table 2-1: Transported cargoes within the scope of this impact assessment

ADN	Already forbidden	25 most transported	Vapour pressure ≥ 10 kPa @ 20°C.	Toxic / CRM	This impact assessment	Description
		UN 1090	UN 1090			Acetone
		UN 1114	UN 1114	UN 1114	**UN1114**	Benzene
		UN 1145	UN 1145			Cyclohexane
		UN 1170				Ethanol or ethanol solution
		UN 1175				Ethylbenzene
		UN 1202				Gas oil or diesel fuel or heating oil, light
	UN 1203					Motor spirit or gasoline or petrol
		UN 1216				isooctene
		UN 1223				Kerosene
		UN 1230	UN 1230	UN 1230		Methanol
		UN 1267	UN 1267	UN 1267	**UN1267**	Petroleum crude oil
		UN 1268	UN 1268	UN 1268	**UN1268**	Petroleum distillates n.o.s. or petroleum products n.o.s.
		UN 1280	UN 1280	UN 1280		Propylene oxide
		UN 1307				Xylenes
		UN 1863	UN 1863	UN 1863	**UN1863**	Fuel, aviation, turbine engine
		UN 1918				Isopropylbenzene
		UN 1993	UN 1993	UN 1993	**UN1993**	Flammable liquid, n.o.s.
		UN 2055				Styrene monomer, stabilized
		UN 2398	UN 2398			Methyl tert-butyl ether (MTBE)
		UN 2789				Acetic acid, glacial or acetic acid solution, > 80% acid, by mass
		UN 3082				Environm. hazardous substance, liquid, n.o.s.
		UN 3257				Elevated temperature liquid, n.o.s., ≥ 100 °C and below its flash point (including molten metals, molten salts, etc.)
		UN 3295	UN3295	UN3295	**UN3295**	Hydrocarbons, n.o.s.
		UN 9001				Substances with a flash point > 60 °C ….
		UN 9003				Substances with a flash point > 60 °C ….
			UN3475		**UN3475**	Ethanol and gasoline mixture or ethanol and motor spirit mixture or ethanol or petrol mixture, with more than 10% ethanol

n.o.s. stands for 'not otherwise specified'
Note: some products are in the previously listed 'top-25', but are not transported in barges. These are not included in this impact assessment
In this study, UN1268 and UN3295 are distinguished in two groups: > and < 10% benzene

2.2 The IVS90 database

The data used for the analysis is retrieved from the IVS90 database (in Dutch: 'Informatie en Volgsysteem voor de Scheepvaart'). The data provided is limited and anonymized, and provided in confidentiality and under supervision of Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and environment).
The Information- and Tracking System (IVS90) is a database for vessel traffic management in all of the Netherlands. It is implemented on locks, bridges and Vessel Traffic Centres (VTS). Vessels that want to pass locks and bridges that open are obliged to call in and forward all the required information to be directly implemented in IVS90. Specifically important is the information about dangerous goods. Since vessels that carry dangerous goods can be recognized by their signaling with blue cones (Dutch: 'kegels'),this leads to the practice that 95-98% of the required information is available in IVS90. On rivers and fairways without locks (route Rotterdam –Germany), VTS are collecting the IVS90 information in the same way as on bridges and locks and on the same grounds. Vessels with dangerous goods on the way from Rotterdam to Germany and vice versa are also obliged to deliver the required information to the VTS centres along the river, which makes the information also for this transport corridor highly reliable. The information in IVS90 is for more than 95% accurate. On the Rhine to Germany the accuracy of data not classified as dangerous goods is less accurate.

The dataset entails the following items:

- Pseudo Ship Number;
- Ship type;
- Type of ship and load;
- Registration time;
- Origin and destination;
- Signal status for dangerous goods (blue cones);
- Cargo, UN or HS number and total weight.

The **pseudo ship number** is the anonymized number given to a *casco*. *Cascoes* can be shipped independently or as a group. As an independent casco (barge), the ship can hold a single or multiple cargoes. Even so, grouped cascoes can hold single or multiple cargoes.
The **type of ship** (independent or group) and load (single or multiple) is specified in the dataset.
The **registration time** refers to the latest registration time at any IVS90-linked gate (lock, bridge, etc). The registration time thus refers to *any* point in time during shipment.
The **origin and destination** are specified by country and city.
The **signal status** shows the number of signals (cones) handled.
Cargo is detailed by HS-number (Harmonised System) for non-dangerous goods and UN-number (United Nations) for dangerous goods. Since this study is about the degassing of certain UN-numbers, only ships are included that have at least once shipped a UN-numbered good in 2014. The total weight is included in cargo details.

The IVS90 database contains information about the ship's condition, being loaded or empty and/or degassed. Since however the condition information is linked to the registration time, which is any point in time during shipment, this information provides very little certainty about the actual occurrence of degassing before accepting a next load. Moreover, as degassing is free of any costs today on open water, ships may degas while not strictly necessary, just to be flexible in accepting a next cargo.

The main information retrieved from the dataset consists of a frequency of subsequent loads for the studied UN-numbers. Together with an analysis of compatibility for these subsequent loads (section 2.3), this gives an estimate of *necessary* degassing in 2014. Extrapolating market conditions and prospected legislation then brings us a view of future demand for controlled degassing.

The dataset holds minor gaps and errors. For example, UN-codes are missing when multiple products are shipped. Also, some records may appear double or are assumed to be missing. Based on our analysis, the total of incomplete, missing or erroneous records is assumed to be <5%.

Besides the checks on the consistency of the database described above, the correctness of the database entries itself is important. A ship master is responsible for the data that is sent to IVS90 receivers. This data is ought to be consistent with its transport documents. In the Netherlands, also the UN-number of the cargo is reported in transport documents. It is assumed to be unlikely that ship masters would intentionally provide discrepancies between the different registration systems.

2.3 Compatibility of cargoes

When a product A can be loaded in a tank that was previously emptied from product B without degassing, product B is considered compatible with product A. In other words: product B stays within the quality specifications when it is mixed with remaining liquid and vapour cargo tank residues of product A. It should be noted, that A is not necessarily compatible with B. For example: naphtha can be loaded in tanks emptied from benzene. However, benzene can often not be transported in a tank that contained naphtha before.

To get from 'number of cargo changes' to 'number of degassings', we need to know in which cases degassing is needed. This requires knowing exact shipment details, including the compatibility of the shipped cargo.

Since the available cargo information is based on UN-numbers, our approach to compatibility is also based on UN-numbers. Table 2-2 provides the assumed compatibility of product combinations occurring in the IVS90 database from the year 2014. Only cargo changes where a product with an UN-number within the scope of this impact assessment (see section 2.1) is the preceding cargo, are included in this table. The table is based on the following assumptions:

- Changes to the same UN-number are regarded 100% compatible when the UN-number refers to homogenous bulk chemicals[4]. Consignors in some cases do distinguish products within the same product category from one producer to another. It is however assumed that the logic of full compatibility between homogenous bulk chemicals is valid for most cases;
- Changes to the same UN-number are regarded 100% compatible when the UN-number refers to a mixture (for example: UN 3295 Hydrocarbons, liquid, not otherwise specified). Compared to the 'pure' products, this will less often be the case. However, no general information nor specific cargo change information is available (see below);

The only available general compatibility information is from a matrix provided by the VNPI[5] and presented in a 2013 report by CE Delft [15]. This is almost identical to the matrix in a report by the EFOA [16]. A summary of this information is given in annex A2. Further information is not available[6].

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[4] *For example: UN1114 'Benzene'. In other words: not a mixture (such as 'gasoline' or 'flammable liquid').*
[5] *VNPI = Netherlands Petroleum Industry Association*
[6] *During the GRTS-meeting of December 7th 2015 and by e-mail, the GRTS-members have been asked for input and feedback. The general response stated that this information is not available or will not be provided by industry because of anti-trust.*

Available information is summarized for the relevant UN Numbers in Table 2-2. In total 88 unique ‘next cargoes’ were found in 2014 for the given seven reviewed ‘preceding cargoes’. Most of these 88 ‘next cargoes’ are considered not to be compatible with any of the preceding cargoes. Non-compatible cargoes are omitted in Table 2-2.

Table 2-2: Applied compatibility of products based on found following cargoes in 2014 (IVS90 database), given the seven preceding cargoes for this study. Products with only zero compatibility are omitted.

→ Previous cargo → ↓ Next cargo ↓		BENZENE 1114	PETROLEUM CRUDE OIL 1267	PETROLEUM DISTILLATES, N.O.S. or PETROLEUM PRODUCTS, N.O.S. 1268	FUEL, AVIATION, TURBINE ENGINE 1863	FLAMMABLE LIQUID, N.O.S. 1993	HYDROCARBONS, LIQUID, N.O.S. 3295	ETHANOL GASOLINE MIXTURE, >10% ETHANOL 3475
BENZENE	1114	-	0%	0%	0%	0%	0%	0%
MOTOR SPIRIT or GASOLINE or PETROL	1203	0%	0%	0%	50%	0%	0%	0%
KEROSENE	1223	0%	0%	0%	50%	0%	0%	0%
PETROLEUM CRUDE OIL	1267	75%	-	75%	75%	25%	75%	25%
PETROLEUM DISTILLATES, N.O.S. or PET	1268	75%	75%	-	75%	75%	75%	75%
FUEL, AVIATION, TURBINE ENGINE	1863	0%	0%	0%	-	0%	0%	0%
FLAMMABLE LIQUID, N.O.S.	1993	0%	0%	0%	0%	-	0%	0%
METHYL tert-BUTYL ETHER	2398	0%	25%	25%	75%	0%	0%	100%
HYDROCARBONS, LIQUID, N.O.S.	3295	0%	0%	0%	0%	0%	-	0%
ETHANOL AND GASOLINE MIXTURE or E	3475	0%	0%	0%	0%	0%	0%	-

Comments:

- *Aviation fuel (UN 1863) can be transported as both UN1223 and UN1863. Since last mentioned covers a wider range of fuels, compatibility is between 0 and 100%. Applied is 50%.*
- *Most UN1268 contains some benzene. Applied 50% compatible since in some cases products may contain no benzene.*
- *Sources: [15, 16]*

2.4 Necessary Degassings Today

2.4.1 When to degas?

A detailed background on degassing is given in section 1.3. In short, degassing is required when:

- The next cargo is not compatible with the preceding cargo;
- Safety requirements prescribe this (e.g. for repair to the barge including hot-work (welding) or mooring at berth places classified as non-hazardous area);
- The pressure increases above the pressure relief valve pressure setting).

Degassing because of safety requirements occurs only seldom and is therefore not included in this study. Gasses emitted by tankers other than with the use to make the tank(s) product free are not considered as degassing.

Situation today
Degassing is prohibited in most port areas. Degassing occurs when ships sail unloaded from one location (where unloaded) to another (to load). It is assumed that today, because uncontrolled degassing is free, ships will start degassing directly after unloading, to be most flexible in receiving a next cargo. It is therefore assumed that degassing largely occurs in the country of destination of the load.

Future situation
When uncontrolled degassing is prohibited in the future and ships need to apply controlled degassing, this might shift towards ships wanting to degas as shortly as possible before loading, to potentially avoid unnecessary costs.

Assumptions

- Today, because degassing is free, ships will start degassing directly after unloading, to be most flexible in receiving a next cargo;
- Today, degassing largely occurs in the country of destination of the load.

2.4.2 Estimate for the Netherlands

An estimate of the necessary degassings in the Netherlands is quantitatively defined based on the IVS90 database. Details of the methodology and database are provided in section 2.2.

As detailed in Table 2-3, it is found that a total number of 3,303 shippings have led to a necessary degassing in the Netherlands in 2014. This is based on:

- The number of found cargo shifts from a selected UN-number to any other cargo;
- Applied if previous load had its destination within NL (i.e. national shipping or import).

Table 2-3: Necessary Degassings in 2014 in the Netherlands

UN-number	Description	Necessary Degassing 2014 *National shipping and Import*
UN1114	Benzene	241
UN1267	Petroleum crude oil	32
UN1268	Petroleum distillates n.o.s. or petroleum products n.o.s.	2,105
UN1863	Fuel, aviation, turbine engine	106
UN1993	Flammable liquid, n.o.s.	126
UN3295	Hydrocarbons, n.o.s.	670
UN3475	Ethanol and gasoline mixture or ethanol and motor spirit mixture or ethanol or petrol mixture, with more than 10% ethanol	24
TOTAL		3,303

n.o.s. stands for 'not otherwise specified'

The recordings shows that clearly UN1268 results in most frequent necessary degassing: with a number of 2,105 it makes roughly 60% of all degassings. The runner-up is the related UN3295 with 670 degassings. In the 'middle group' we see UN1114, 1863 and 1993. UN1267 and 3475 rarely require degassing.

2.4.3 Estimate for CDNI

A database similar to the Dutch IVS90 was not available for the other CDNI countries for this study. The number of degassings is therefore extrapolated from the Dutch figure. Extrapolation is based on EuroStat data for inland tanker vessels (tonnages, total transport). Table 2-4 provides an overview of the percentages used in the extrapolation.
Corrections have been made for Germany, France and Switzerland. The figure for Germany is corrected for its area. EuroStat provides data on member state's national level. Though the CDNI officially covers all of Germany, this study focuses on the Rhine area only – in line with previous studies about degassing conducted for the German government [13]. Given the distribution of inland tanker barges in Germany as a whole and the Rhine area specifically for 2012 [13] the EuroStat data is corrected with this percentage[7]. France has provided data for 2014 for the France CDNI-region, split down in the Rhine area (90% of total unloaded) and Northern area (10% of total unloaded). This concerns data on the most transported prodcuts). Switzerland is not an EU member state, hence no EuroStat data is available. The Rhine covers a lenght in Switzerland of approximately 20 km, in mostly port/city area. Though degassing is prohibited in this area today, we still make an estimation of necessary degassings. These degassings today either occur in a controlled manner, or in other areas (e.g. France). Necessary degassing is estimated at 0,5% of the Dutch level.

Table 2-4: Transport by inland waterway tanker barge for CDNI countries

Country	Inland waterway shipping by tanker barge, (1000 tonne)	Percentage (%)
Netherlands	106,068	100.0%
Germany (Rhine area)	25,123	23.7%
Belgium	56,327	53.1%
France (Rhine and North area)	3404	3.2%
Luxembourg	388	0.4%
Switzerland (Rhine Basel area)	530	0.5%
TOTAL	191,885	180.9%

The distribution given in Table 2-4 is used to extrapolate the number of degassings for 2014 in the Netherlands to the CDNI countries as a whole. It is also used to predict the number of degassings in future scenarios. Though we are aware that changes per country may occur (e.g. inland waterway shipping has been declining over the years in Germany, and has been increasing in Belgium), inland shipping for CDNI countries as a whole shows a growth similar to that of the Netherlands. A detailed overview of past and predicted development of inland waterway shipping in the CDNI countries is included in Annex A2.

A prospection of future necessary degassing in the CDNI area depends on more than the above. An estimate is given in section 4.4., after adding transport scenarios (section4.4) and implications of the implementation of the restriction (section 3).

[7] *From report [13], tabel 21, tonnages 'Rheinstromgebiet gesamt' is devided by tonnages 'Deutschland insgesamt', resulting in about 1/3. This is multiplied with the numbers transported volumes from Eurostat as used for all CDNI countries.*

3 Implementing degassing restrictions in the CDNI convention

3.1 Phased approach

Reasons for a phased approach
After the prospected agreement on the adjustments to the CDNI convention by the Conference of Contracting parties regarding the restriction on degassing, it will take a considerable period of time before the restriction comes into force in the individual countries due to ratification and implementation in national laws. We expect the first restriction will be effective not earlier than January 1st 2019.

A phased introduction enables all parties to develop expertise and learn from a small(er) scale restriction and implement these lessons learned before a full scale restriction becomes effective. As a first step, lessons should be learned from controlled degassing activities in the port of Antwerp and ATM Moerdijk.

Additionally, a phased approach allows for spreading of investment costs, making it easier to finance required facilities. The period until the first phase can be used to make necessary preparations for the upcoming degassing restriction. This provides the certainty that is needed for necessary investment decisions. The current uncertainty on what will come makes that currently no (investment) decisions are made.

Concluding, the introduction should be practically feasible for the market and politics.

Threats of a phased approach
On the other hand, starting with a small scale degassing restriction might make investment decisions harder if degassing facilities are designed on a full scale restriction (i.e. a smaller scale restriction results in lower income in the first years and subsequently a weaker business case). The extent of this effect will be determined by the economy of scale[8] and modularity of the installations. A fully modular system can be extended just before a next phase will become effective, like the Vaporsol container-based modular system.

3.2 Applying a phased approach

The number of phases should be limited in our opinion. The learning curve will not improve with more steps and many successive changes will result in indistinctness. In section 1.3, we split down the effects of a degassing restriction in effects on (1) logistics, (2) man and environment and (3) transport cost. These effects with respect to a phasing in the restriction should be seen as:

1. Man and environment: include the most harmful substances in the first phase and less harmful substances in later ones;
2. Logistics: a reasonable spread in transport volumes;
3. Transport cost: spread additional cost over the phases.

[8] Economy of scale: cost advantages due to size, output, or scale of operation, with cost per unit of output decreasing with increasing scale as fixed costs are spread out over more units of output.

3.2.1 First phase

As presented in section 2.1, the seven UN-numbers included in this impact assessment result in a high score on ‘man and environment’. For this reason, it would make sense to include all of these in a first phase. Additional reasons to include these all in a first phase:

- Just UN1268 represents about 65% of the total volume in the Netherlands[9], which makes a split of about 50/50% not possible;
- In addition to this, we recommend to prohibit UN1268 (petroleum distillates, n.o.s.) and UN3295 (hydrocarbons, liquids, n.o.s.) in the same phase. We expect that the restriction of one of the two UN-numbers will result in the transport of the same cargoes using the other of the two UN-numbers. The contribution of UN1268 and UN3295 together is almost 85% of the total estimated degassings of the seven reviewed products;
- Since degassing of UN1268 is already forbidden in Germany, it would be wise to include this in the first phase. UN1114 (and in a later stage other benzene containing cargoes as well) is already forbidden in parts of the Netherlands.

Exception for low-benzene content

Since the reviewed products are selected on the basis of the (possible) benzene fraction, it would make sense to distinguish high and low benzene content cargoes that are transported when a phased introduction is needed. High benzene content cargoes transported under the UN-numbers covered by the first phase of the restriction are prohibited to degas while degassing of cargoes with low benzene content transported under the same UN-numbers is not prohibited. A limit concentration often mentioned in the GRTS is 10 vol-%.

We understand the wish and for a split in more and less than 10 vol-% benzene and also the rationale. However, we foresee difficulties in the enforcement. Where the UN-numbers are centrally registered (IVS90), the benzene content is not registered in a tracking system (IVS90 or in another system). Only in unloading forms and transport documents the percentage is mentioned. Enforcement requires therefore adjustments to current registration systems, a new form of registration of the benzene content or inspection of the existing documents during a transport. This will be more difficult than enforcement by UN-number only. However, we noticed a strong wish from various stakeholders to distinguish cargoes with >10% benzene from cargoes with < 10% benzene as a basis for a phased introduction. An effective enforcement is in general and specifically when a benzene content limit will be applied, essential and should be developed carefully as a next step.

We propose a first phase with UN114, UN1267, UN1268 (≥ 10% benzene), UN1863, UN1993, UN3295 (< 10% benzene) and UN3475.

In this study, we assumed for both UN1268 and UN3295 that 40% of the transports is > 10% benzene and 60% < 10% benzene.

3.2.2 Second Phase

We propose a second phase to complete a full restriction of degassing of vapours of hazardous cargoes. The time between these phases should be long enough to implement lessons learned, but also short enough to guarantee a continuous improvement and avoid slackening. We believe a period of two years in between phases is suitable to achieve both. With the start of the first phase set at 2019, this results in the second phase entering into force in 2021.

[9] *We expect this is similar in the other CDNI countries.*

The Top-25 (most transported, see Table 2-1) is the most logical basis to define future phases. Based on transported volume, the suggestion is to include all Top-25, including the < 10 vol-% benzene cargoes transported under the phase 1 UN-numbers.

Note that though this advice on a phased approach entails the total Top-25 products, the impact assessment only includes the selected seven, and the estimated required degassings and costs in section 4.5 do not include a second phase with the remaining Top-25 products.

4 What do we need to facilitate controlled degassing?

When a restriction comes in place, the supply chain actors should be able to comply with this restriction. For this reason, it should be known what type of facilities are needed, how many are needed and what the costs are.

4.1 Types of installations

4.1.1 On-board, floating, on-shore

Degassing installations can be categorized in on-board, floating and on-shore installations. This study focuses on **on-shore installations**. Such installations are expected to have a best fit with a facilitating role, since these are the easiest to operate and can be accessed by many barges.

4.1.2 Technologies

Many different technologies for the treatment of gases have been developed over the years. Since restrictions are not implemented yet, none of these are currently commercially operational in the sector of degassing of inland tanker barges. Based on previous research [9], several technologies have been reviewed, including thermal treatment (with energy recovery) and (cryo-) condensation.
Each technology has different advantages and disadvantages (e.g. costs, level of final emissions, product recovery). A specific interest is the possibility of recovering product for reuse.
This study does not aim to point out a preferred technology. The different technologies are reviewed to estimate an average cost for controlled degassing per barge. The costs of controlled degassing are further discussed in section 4.3.

4.2 Locations for degassing installations

4.2.1 Considerations in location selection

Industrial clusters
In the current situation without degassing restrictions, uncontrolled degassing is preferably done directly after unloading, while sailing, to be most flexible for receiving a next cargo. In a new situation when degassing is restricted, controlled degassing is preferably done directly before loading, to be most flexible in avoiding additional costs of degassing. For this reason, the most convenient locations for installations for controlled degassing are close to industrial clusters, where most loading takes place.

Routes
Industrial clusters itself are often very crowded, leaving little space for degassing installations. And though terminals are in most cases equipped with installations for the treatment of gases, the capacity of these installations and berths is limited. For this reason, degassing at a terminal will mostly not be a preferred option.
Another option is to locate degassing installations on the skirts of the mostly frequented sailing routes, just outside the industrial areas. There are some limiting conditions in the selection of suitable locations. For example, in the Dutch situation:

- Ships are not allowed to berth/anchor on the main transport ways *(Dutch: 'hoofdtransportas')*;
- Ships should be able to sail away easily at any time.

Figure 4-2 on page 19 gives an overview of the main waterways in the CDNI area (focus on the Rhine area; some parts of the Netherlands and Germany are not on the map).

Blue Cone Berths

Deployment of a degassing installation will attract ships and possibly induce a queue. Queuing areas in the form of blue cone berths are required relatively close to the degassing installation. Like the situation at terminals today, blue cone berths do not necessarily need to be very close to the installation, and not every installation requires its own queuing berth. E.g. Port of Antwerp only has two blue cone berths; Port of Rotterdam only has three.

Information about the blue cone berths was available for the Netherlands only. An overview of blue cone berths is given in Figure 4-1 [18]. The number of blue cone berths is thought by some to be critical already today in Belgium and the Netherlands, and introducing extra queuing capacity would therefore require the installation of extra blue cone berths. As the creation of such a berthing place is reckoned to be in high contrast with the costs of degassing installation and direct berth itself this is not thought to be a leading issue, nor do existing blue cone berths determine the best location of a to be installed degassing facility. After all, we do expect the availability of blue cone berths is not a leading issue in the introduction of degassing restrictions.

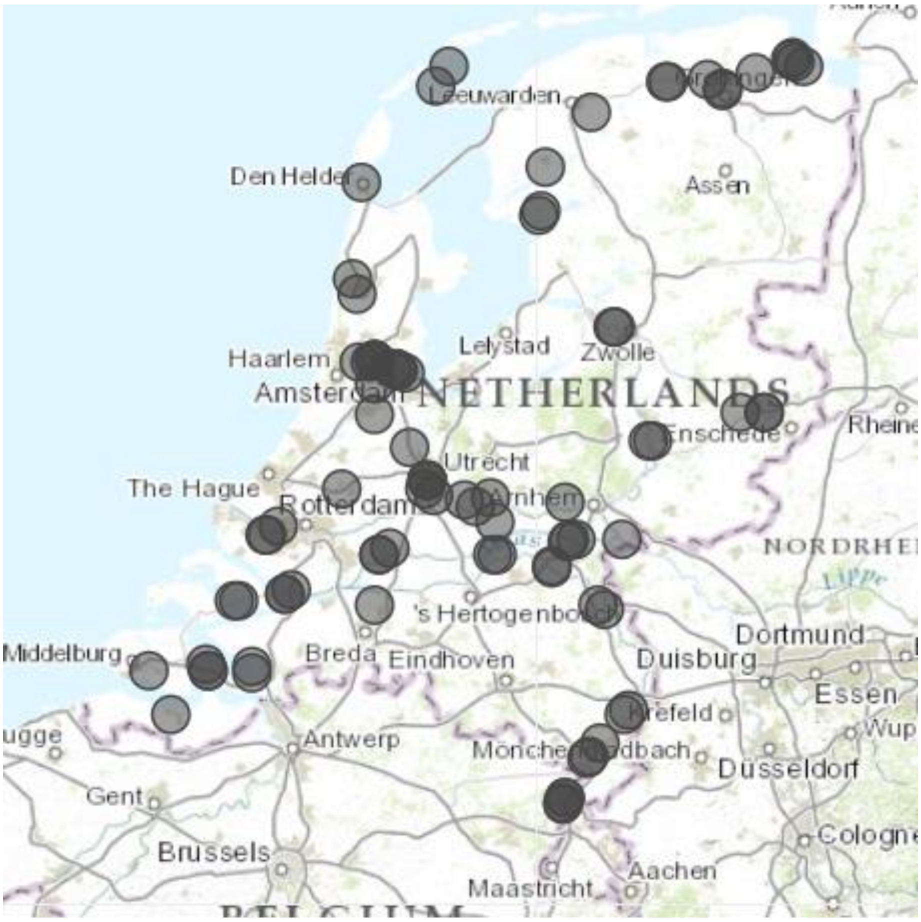


Figure 4-1: Blue cone berths in the Netherlands

4.2.2 Number of installations

Capacity per installation

The capacity of degassing installations is mostly limited by the on-board infrastructure (piping). The time required for degassing is assumed to be 8 hours (see also section 4.3). With a 100% utilization, this results in 365 * 24 / 8 = 1095 as theoretical maximum per connection. A more realistic utilization is 60-70%. The business case for degassing installations is built upon ~700 barges per installation per annum (see also section 4.3). Hence, this is the *minimum* of barges per installation.

Number of installations

Assuming the Optimal Market Development scenario (see section 4.4) with roughly 3000 controlled degassings per annum (in 2015, when all seven studied UN-numbers are included in the regulation), this results in a *maximum* of 3000 / 700 = 5 (rounded up) installations. A suggestion for locations in the Rhine area is given in the following section. This shows that coverage with 5 installations might be critical, especially in the outskirts. Lowering the utilization rate, the number of installations can be increased to support geographical spreading. For now, the model calculates with 5 installations.

4.2.3 Suggested locations in the Rhine Area

The regulation covers the full CDNI area, and will take effect in all areas at once. This implies that facilities for coping with the regulation should cover the full area from the very start. As indicated in section 4.4 (Optimal Market Development Scenario) many response mechanisms are expected. Controlled degassing at an on-shore installation is only one of them. As the direct Rhine area (Rhine and Rhine delta) is the most used shipping route, this study focuses on the facility of degassing installations in this limited area. It should be noted that some CDNI regions, for example the North of France, are far from the Rhine and may need additional degassing facilities. The locations of these installations will be based on the remoteness of other degassing installations and not on the required degassing capacity. These installations might differ in type or capacity from installations in areas with a higher degassing capacity demand.

The assumption is made that a barge will make a detour of 2 hours on average to reach a degassing facility. With ships sailing 20km/h[10] on average, the radius with the given detour time is 40 km. As exact sailing routes and frequencies are unknown but assumed to differ largely, it is hard to predict the exact time required for a detour. For example, it might require a direct return, or be solely a deviation towards a next destination.

Figure 4-2 [19] gives an overview of the main waterways in the Rhine delta. Following the reasoning as outlined in the above related to convenient points of degassing, minimum and maximum number of installations and coverage of CDNI area, Figure 4-3 gives a suggestion for a distribution of five suggested degassing installations. This rough site selection points out locations close or on the way to an industrial cluster:

- Antwerp;
- Rotterdam;
- Close to Nijmegen;
- South of Bonn;
- South of Frankfurt.

[10] *http://www.surfsleutel.info/binnenvaart/inbeeld.htm*

These include the locations of existing degassing facilities in the Port of Antwerp and at ATM Moerdijk. The capacity and utilization of these installations is unknown and the assessment hereof is not part of this study.

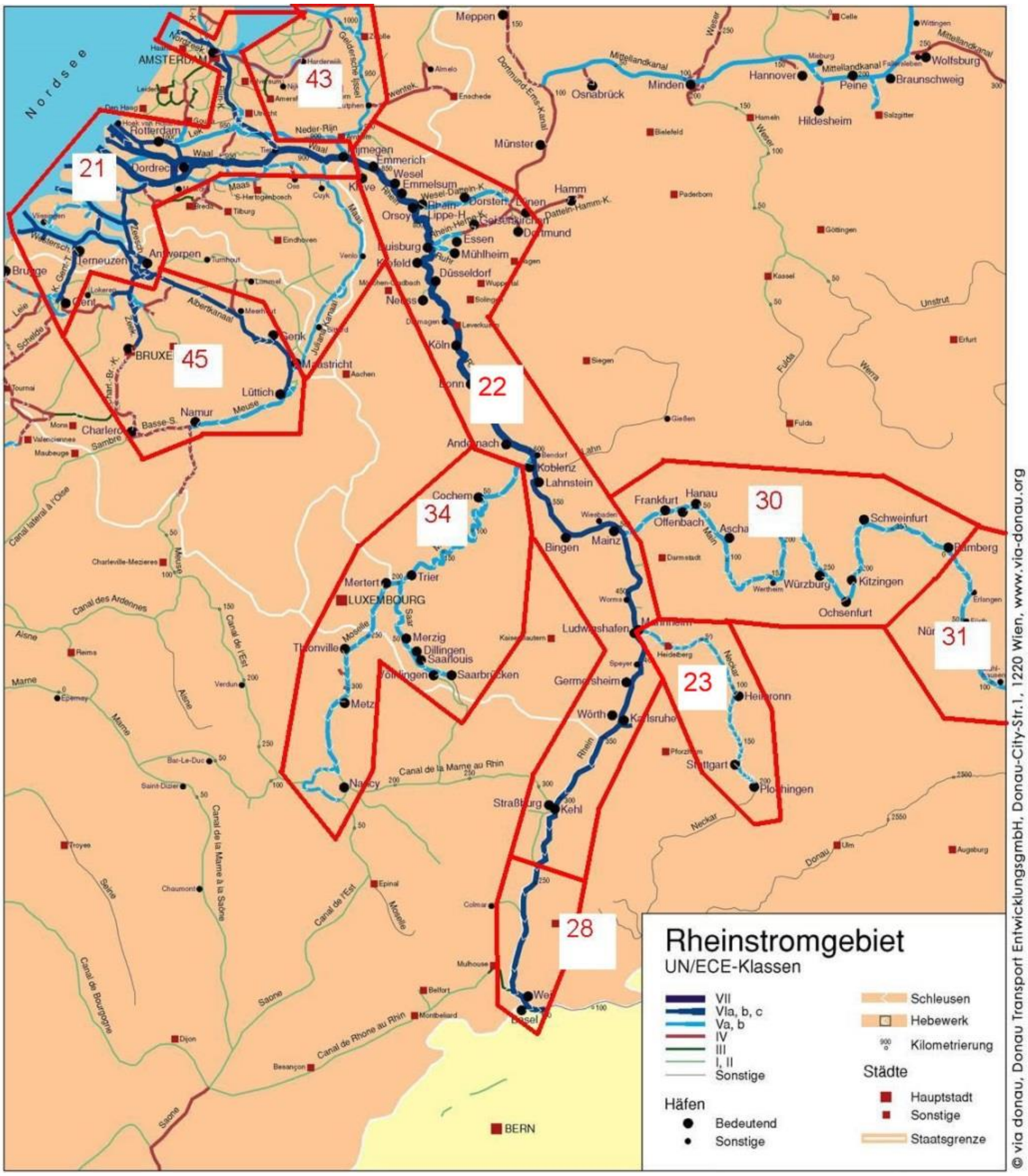


Figure 4-2: Overview of waterways in Rhine area [19]

Figure 4-3: projected locations for on-shore controlled degassing facility. ATM Moerdijk currently has one degassing facility with unknown capacity. Antwerp currently has one on-shore and one mobile installation (one cryogenic, one active carbon), both with unknown capacity and therefore calculated as one. Other installations are projected east of Nijmegenl, south of Bonn and south of Frankfurt.

4.2.4 Suggestions for phased implementation

Eventually all products harmful for humans or the environment are expected to be part of the regulation. Part of this study is the analysis of the need for a phased implementation, implementing restrictions for different UN-numbers at different times. Based on the topics discussed in this section 4.2 it is suggested to reach a level of ~3000 degassings per annum as soon as possible, so allowing for a full coverage of the Rhine area and backing a business case for each individual degassing installation. A detailed suggestion for phased implementation on basis of UN-numbers is discussed in section 3.

4.3 The cost of degassing

The cost of controlled degassing depends on many different factors, including CAPEX, OPEX, idle time etc. Each aspect is analysed for the three reviewed technologies and briefly discussed below. Table 4-1 summarizes the estimated costs. The ship type used is a class Vb (CEMT) or standard tanker barge (110m) [12]. The capacity of the installations is assumed to be all equal and set at 1500m³/h.

Equipment

Equipment costs are given based on previous research [9]. The equipment cost includes the investment for the equipment (installation), and is included in the CAPEX + OPEX per barge (depreciation of 5 years).

Berthing Facility
A berthing facility is required where no berth is already available (green field). The estimation is based on calculations for a berthing facility in a port area (no dredging required). Details are given in annex A5. Additional equipment costs to connect the barge to the installation (loading arm or hose tower) are estimated at 20% of the cost of the berthing facility. Costs are included in the CAPEX + OPEX per barge (depreciation of 5 years)

Costs Idle Time
When a ship applies controlled degassing, it cannot use the time spent for degassing for transporting cargo. This time is termed idle time.
A ship is degassed when the concentration in the tanks is below the Acceptable Vent Free Level (AVFL). This AVFL equals 10% of the Lower Explosion Limit at measuring conditions [6].
The time needed for degassing depends on the capacity of a degassing installation, the volume of the barge tanks, the temperature and the type of product in the tanks. More volatile products reach the AVFL in a shorter period of time than less volatile products. For this study, we assume an average time of degassing of 8 hours. This is based on experiments with several types of installations and claims of suppliers [7,8,9,10,11]. The total additional waiting time for as ship is assumed to be 10 hours, including sailing time to the installation and mooring.
The costs for ships (class IV) being idle is estimated at 200€/h [12].

Cost Sailing (Detour)
The average time for a detour is estimated at 2 hours, as also discussed in section 4.2.3. In 2 hours a ship is estimated to sail 40 km. With a cost of 20 €/km [12], the cost of making a detour is calculated by 2 hours idle * 200 € + 40 km * 20 € = 1200 € per degassing.

Cost Berthing
Costs for berthing are not included in the operational expenses and therefore calculated separately. Costs for berthing includes the hourly fee for occupation of a berth (and use of any facilities). Berthing is estimated at 8 hours (time for degassing). Hourly rate is estimated at 150 €/h.

Total Costs per Degassing
The total costs per degassing are summed up in Table 4-1 and comes down to roughly 6450 € per degassing, with an accuracy of ± 30%. Large influencers include energy prices, utilization rate of the installation, initial presence of berthing facility and mostly the time required for degassing.
It should be noted that the largest costs by far are related to the ship being idle / sailing / berthing. In other words, time shows to be a great denominator. Today, controlled degassing takes place using the piping infrastructure on the barges (as these itself need to be degassed). This on-board infrastructure generally forms the bottleneck in increasing the speed of degassing.

Table 4-1: Typical cost of degassing based on a capacity of about 1,500 Nm³/h, based on [8,9,10]

	Incineration (+E Recovery)	*Condensation*	*Cryo-Condensation*	AVERAGE
Vessel type (CEMT)	Vb	Vb	Vb	IVb
Capacity Installation (m³/h)	1500	1500	1500	1500
Equipment Cost (€)	750.000	1.500.000	800.000	1.000.000
Berthing Facility (€)	1.800.000	1.800.000	1.800.000	1.800.000
Loading arm, utilities (€)	360.000	360.000	360.000	360.000
Depreciation (years)	5	5	5	5
Equipment Cost + OPEX / barge (average)	750	1.000	1.750	1.200
Total CAPEX + OPEX / barge	**1.533**	**1.825**	**2.701**	**2.058**
Idle Time (degassing, mooring) (h)	10	10	10	10
Cost idle / h	200	200	200	200
Total Cost Idle Time	2.000	2.000	2.000	2.000
Time sailing (detour) (h)	2	2	2	2
Sailing speed (km/h)	20	20	20	20
Cost sailing / km	20	20	20	20
Total Cost Sailing	1200	1200	1200	1200
Time berthing (h)	8	8	8	8
Costs berthing / h	150	150	150	150
Total Cost Berthing	1.200	1.200	1.200	1.200
Total Cost per Degassing	**5.933**	**6.225**	**7.101**	**6.458**

4.4 Transport scenarios

When an uncontrolled degassing restriction comes into force, the transport sector will respond to it by re-optimizing the planning of transports with the newly given set of rules. Sending all ships with vapour residues covered by the restriction to a degassing station is only one of the options.

Other possible options include:

- Dedicated transport;
- Large-volume barges with dedicated tanks for two products;
- Revise generic pre-cargo lists;
- More clustering in product families.

Recently, Royal HaskoningDHV studied these alternatives within the scope of the project ‘Recover C’ [11]. From this study, we learned that the sector is already experimenting with such optimizations. However previous studies on the effects of market response to changing legislation show that it remains difficult to predict the exact future. Therefore we have worked out two scenarios showing the bandwidth of possible response. The growth in emissions from degassing are assumed to be equal to the growth in transport volume.

We’ve analysed two scenario’s:

- The Business As Usual (BAU) scenario: This is based on an expected autonomous development of the inland tank vessel market in the coming ten years.
- The Optimal Market Development (OMD) scenario: This is based on the same expected autonomous development of the inland tank vessel market as in the BAU scenario, completed with an estimated influence of transport optimization by the several supply chain actors.

The BAU scenario

The BAU scenario is based on the 2014 IVS90-data, completed with an estimate of the future development.

Motivations for increased transport by tanker barges:

- Due to the current low oil prices, we expect for the short term an increase in demand for storage and as a result more transport [5].
- For the longer term, we expect a trend in the modal shift towards transport by ship. The competitive position of inland tank vessel transport is good, so an increasing share of the total transport volume is possible [3]. Especially the transport of chemicals has potential for volume growth [5].
- The chemical industry shows a moderate growth [5].

Motivations for decreased transport by tanker barges:

- Less ‘floating storage’[11] is needed due to increased land storage [5];
- General stagnation is expected due a decreasing use of fossil products in the long term [4] and;
- Shift of production capacity to other parts of the world [2].

Based on above (opposite) trends, we assume a moderate growth of inland tank vessel transport in the period 2015 – 2025. The Dutch Rabobank estimates the sector (inland shipping, including tankers) growth for the coming years to be 1,5% in the Netherlands [2]. The tanker branch perspectives are above average in the total inland shipping sector [5]. In Germany, we observe a stagnation and even small decrease in transported volumes due to another modal split.

[11] Cargo is being stored in tankers at anchor, actually "hedging" that prices will fluctuate enough to offload it in a period of high(er) prices.

We assume a growth of 2% per year in the period 2015 – 2025 in the CDNI area. This average growth reflects the trend over the past years based on Eurostat data (1-3% growth on average for CDNI countries as a whole).

The OMD scenario

The OMD scenario is the BAU scenario, completed with an estimated market development as response to a degassing restriction.

When degassing of vessels loaded with gasoline was restricted in the Netherlands and Germany (Since 31/12/2005 uncontrolled degassing of emptied barges having contained gasoline (UN1203) is forbidden according to EU Directive 94/63/EC), no strong increase in degassing facility demand was noticed. Apparently, the market seeks and finds solutions to avoid controlled degassing. These solutions have been previously studied [11] and include, amongst others, more dedicated transport, accepting more pre-cargo's as compatible, deploying large-volume barges to two products, flushing of tanks with next cargo product and more clustering of product families.

Possibly also other, unwanted mechanisms may be used. These mechanisms include the transport of the same product using another UN-number (not covered by the restriction), degassing in areas without degassing restrictions and illegal uncontrolled degassing because of lack of law enforcement. The likeliness of these types of mechanisms to occur decreases when the restriction covers more (generic) UN-codes and is internationally enforced. This is expected to happen when the restriction becomes part of the CDNI convention.

A quantitative estimation of the effect of market development is not part of this study. A qualitative estimation has been assessed by interviews with 'the market', including:

- Ship-owners;
- Consignors;
- Receivers.

Based in the interviews and the abovementioned effects, the effect of market development is estimated at 60%. In other words: the number of degassings in the OMD scenario is 40% of the number of degassings in the BAU scenario.

4.5 Total costs of degassing for whole supply chain

The total costs for the supply chain are given in Table 4-2 for the CDNI area for the OMD scenario. The timeline starts in 2019 and runs until 2025, with the first phase implemented in 2019 and the second phase implemented in 2021. The phased implementation plan is discussed in section 3. The table shows that full implementation of the seven reviewed UN-numbers results in a total supply chain cost of ~19 million Euro per year (in 2025 for the OMD scenario).

Table 4-2: Estimation of number of degassings, required number of installations and total costs for the supply chain for the OMD scenario in the CDNI area.

CDNI Area		2019	2020	2021	2022	2023	2024	2025
OMD	Necessary Degassings	1304	1330	2735	2790	2846	2903	2961
OMD	Required on-shore installations	2	2	4	4	4	5	5
OMD	Investment Costs (€)	2.000.000	-	2.000.000	-	-	1.000.000	-
OMD	Total cost for degassing (€)	8.420.000	8.590.000	17.670.000	18.020.000	18.380.000	18.750.000	19.120.000

5 Cost-benefit analysis

5.1 Introduction

Section 4.5 provides the total costs for the sector of the suggested degassing restrictions. As a consequence of these restrictions, a certain amount of emissions to the atmosphere is avoided. It is common in assessments of emission reducing technologies to express the total costs and the avoided emission (or annual reduction of emissions) as the cost-effectiveness (CE) of a technology. Also in the preparation or implementation of environmental policies cost-effectiveness is often used.
The CE is the cost per unit pollutant avoided or reduced, or:

$$CE = \frac{annual\ cost}{annual\ reduction\ of\ emissions}$$

The cost-effectiveness helps to rank abatement options. In this case, we can compare the cost-effectiveness of the proposed restrictions with other benzene and VOC emission reducing measures.

For industry, cost-effectiveness is described in the European Best Reference document (BREF) ‘Economics and cross media effects’. This document provides for several EU countries levels of cost-effectiveness for NO_x, SO_x and also VOC. This document has been formally adopted by the European Commission under the IPPC Directive (2008/1/EC), but is rather old. Since no newer (draft) version is available, this is still the document in force. More recent are numbers in the Dutch environmental legislation. We will use both documents in this cost-benefit analysis.

The annual cost (the numerator in above formula for CE) is provided in section 4.5. The avoided emissions (the denominator in above formula for CE) are estimated in section 5.2. The concluding cost effectiveness is given in section 5.3.

5.2 Avoided emissions

In this impact assessment, the focus in on required controlled degassing capacity. This capacity is based on the current number of degassings and supply chain optimization from the market response to a restriction. This market response results in a number of avoided degassings. The calculated capacity for degassing installation is based on the remaining degassings. However, the avoided degassings also result from the restriction. For this reason, the avoided emission in the calculation of the cost effectiveness are based on the sum of avoided degassing and controlled degassings at installations.

The avoided VOC emissions are calculated for each of the seven products:

$$E_i = N \times |L + \{V \times [(C_{VOC}^{SAT} \times S) - C_{VOC}^{AVFL}]\}|$$

E_i	= avoided emission of product i in the year 2021 (kg)
i	= product i (UN1114, UN1268, …)
N	= number of degassings in the year 2021
L	= liquid remains in tanks and piping (kg)
V	= total tank volume per degassing (m^3)
C_{VOC}^{SAT}	= equilibrium vapour concentration of a saturated vapour above liquid of product i (kg/m^3)
C_{VOC}^{AVFL}	= Acceptable Vent Free Level; vapour concentration at the end of the degassing (kg/m^3)
S	= saturation factor of actual vapour; fraction of C_{VAP} (0…1)

Finally, all VOC emissions of all seven products (i = 1…7) are summed up:

$$E_{VOC} = \sum_{i=1}^{i=7} E_i$$

E_{VOC} = VOC emissions from all seven product in the year 2021.

For the total emission of benzene the same approach is applied.

Number of degassings

We calculate the cost-effectiveness for the year 2021. The basis is scenario 0 (best guess scenario; see section 6.3). The number of degassings is calculated for each of the seven reviewed products, according to the methodology described in previous chapters. Table 5-1 is a summarizing table.

Table 5-1: Typical Number of degassings in 2021 for CDNI for the seven reviewed products

Product	Number of avoided degassings in 2021
UN1114	501
UN1267	64
UN1268 > 10% benzene	1745
UN1268 < 10% benzene	2618
UN1863	220
UN1993	260
UN3295 > 10% benzene	552
UN3295 < 10% benzene	828
UN3475	49

Vapour concentrations

Emissions from degassing are defined by the actual vapour concentrations in a barge's tanks after unloading (this is C_{VOC}^{SAT} x S) and the final vapour concentration after degassing (C_{VOC}^{AVFL}). This actual vapour concentration is estimated by relating it to the saturated vapour concentration, which in turn is calculated per product.

It is known that the actual vapour concentration in the tanks is lower than the saturated vapour concentration. A well accepted saturation factor is 56%, based on international standards. This value originates from the American AP-42 [23] and is used in European studies [24] and EU member state standards, including the Dutch 'Handbook emission factors' [25]. This saturation factor is used for all calculations in this cost-benefit analysis.

The saturated vapour concentration differs by product. The saturated vapour concentrations can be calculated from the product's vapour pressure. For UN1114 (benzene) this is the most straightforward since this is a pure substance. All other six products are mixtures; some with a constant composition (UN1863), others with a highly fluctuating composition (such as UN1268 and UN3295). For this reason, the vapour concentration of benzene is reported as a single value, others as a range, resulting in minimum case and a maximum case. The values are taken from a 2013 report by CE Delft where available; Others are determined by calculations (see Table 5-2). The final vapour concentration is defined as the vapour concentration after degassing. Tanks are degassed until the concentration in the tanks is below the Acceptable Vent Free Level (AVFL) which corresponds with 10% of the Lower Explosion Limit (LEL). For most products, this is in the range of 3 – 6 g/m^3 [26]. In this cost-benefit analysis we apply a value of 3.5 g/m^3 for all products.

All vapour concentrations are tabulated in Table 5-2.

Table 5-2: Vapour concentrations, minimum and maximum case

Products	VOC saturated vapour concentration (g/m^3)		Saturation factor (% of saturation)	Actual vapour concentration (g/m^3)		Final / AVFL vapour concentration (g/m^3)
	min	*max*		*min*	*max*	
UN1114 [1)]	320	320	56%	179	179	3.5
UN1267 [2)]	121	1615	56%	68	904	3.5
UN1268 [1)]	30	450	56%	17	252	3.5
UN1863 [3)]	16	16	56%	9	9	3.5
UN1993 [1)]	150	1180	56%	84	661	3.5
UN3295 [1)]	20	2350	56%	11	1316	3.5
UN3475 [4)]	620	620	56%	347	347	3.5

[1)] Source: [15,22]
[2)] Based on crude oils Reid Vapour Pressure range of 10 – 70 kPa [25], a molecular weight of crude oil vapour according calculation method of appendix A3 in [25] and ideal gas law. This results in a true vapour pressure in the range of 4.4 – 60 kPa and the reported saturated vapour concentrations.
[3)] Based on typical kerosene vapour pressure of 0.3 kPa at 20°C, molar weight of vapour of 53.8 g/mol [25] and ideal gas law.
[4)] We assume a E85 fuel (85 vol-% ethanol, 15 vol-% gasoline) as minimum case and E10 as maximum case. Mole percentages are assumed equal to volume percentages (approximation). The mixture vapour pressure is calculated from the vapour pressures of gasoline (30 kPa @ 20°C) and ethanol (5.9 kPa @ 20°C). For example E10: 0.1 x 5.9 + 0.9 x 30 = 28 kPa. The vapour phase will be dominated by gasoline vapour, so we assume the vapour molar mass to be equal to gasoline in both cases.

Amount of liquid and vapour to remove

In the tanks, both liquid and vapour is present. To lower the vapour concentration in the tank, first all liquid needs to be evaporated. During this process, the vapour concentration remains more or less constant. When all liquid is evaporated, the vapour concentration starts lowering.

The study ‘Update estimate emissions degassing inland tank vessels’ from CE Delft [15] estimates the liquid remains to be typically 0.00245% of the cargo, or 58 litres per typical vessel of 2,000 m^3.

As an example, we show the case of UN1114 at 20°C:

- From liquid remains: 58 L x 0.87 kg/L = 50 kg;
- From vapour: 0.321 kg/m^3 x 2,000 m^3 = 642 kg;
- $E_i = N \times |L + \{V \times [(C_{VOC}^{SAT} \times S) - C_{VOC}^{AVFL}]\}| = 501 \times |50 + \{2{,}000 \times [(0.320 \times 0.56) - 0.0035]\}| = 201 \text{ ton.}$

Benzene fraction

The cost-effectiveness is expressed both in terms of total VOC and specifically benzene content. The estimated benzene content is taken from literature and shown in Table 5-3.

Table 5-3: Estimated average benzene content in products

Product	Estimated benzene content (%)	Source
UN1114	100%	
UN1267	0.2%	Crude oils contains typically up to about 1 mass-% benzene. 0.2% is an average value.
UN1268 > 10% benzene	30%	Pygas is a common product in this group. This has a high benzene content of typically around 30%.
UN1268 < 10% benzene	5%	Wide range of products, including naphtha, with wide range of benzene contents. 5% is expert judgement.
UN1863	0.02%	Benzene content very low.
UN1993	5%	Expert judgement
UN3295 > 10% benzene	30%	Assumed equal to UN1268
UN3295 < 10% benzene	5%	Assumed equal to UN1268
UN3475	0.5%	Maximum allowed in gasoline is 1 vol-%, but known to be lower. 0,5% is expert judgement.

5.3 Cost-effectiveness

Cost-effectiveness of the proposed restrictions

Based on the Optimal Market Development scenario, the cost-effectiveness, resulting from the avoided emissions (section 5.2) and total costs is shown in Table 5-4. The minimum and maximum cases are based on the minimum and maximum vapour concentrations as given in Table 5-2.

Table 5-4: Cost-effectiveness of proposed degassing restriction based on 2021 and seven selected products

	Maximum emissions case (€ / kg avoided emission)	Minimum emissions case (€ / kg avoided emission)	Average case (€ / kg avoided emission)
CE reduction VOC emissions	3	27	15
CE reduction benzene emissions	17	73	45

Benchmark VOC

In industry, the IPPC BREF-document 'Economics' from 2006 [27] is the only legal reference. This document does not report a single range of cost-effectiveness. It does discuss ranges in a number of EU countries. Two of these are also CDNI-countries: Belgium and the Netherlands. For these countries VOC-emission reduction techniques are considered cost-effective in the range of 7.5 – 20 € / kg VOC, based on the BREF document 'Economics' from 2006 [27]. When we correct for the actual European inflation in the past 10 years, this is about 9 – 23 € / kg. Cases where harmful VOC such as benzene are emitted are explicitly excluded from this range. In the Netherlands, a 2010 report by engineering consulting firm DHV (now Royal HaskoningDHV) reports [28] a range of 13 – 23 € / kg VOC (14 – 25 € / kg in 2016, corrected for inflation). This resulted later in an inclusion in the Dutch legislation (Dutch: Activiteitenbesluit, table 2.7) of 8 – 15 € / kg VOC. In this Dutch legislation, the CE-range of x – y € / kg is interpreted as:

- CE < x: Emission reduction measure is cost effective;
- x < CE < y: Assessment range. Competent authority prescribes CE on case-by-case basis;
- CE > y: Emission reduction measure is not cost effective.

There is no basis to prefer one of the given CE-ranges. In our discussion below, we therefore include all ranges.

Benchmark benzene

Specific cost-effectiveness values for benzene are not available. It should however be mentioned that benzene is carcinogenic and mutagenic and the use of benzene is restricted in Europe within the framework of the REACH regulation. In many countries, emission regulation of these substances is more strict than of other VOC. For these substances, emissions should be minimized and zero-emission should be pursued. For these substances, higher abatement costs compared to VOC are often accepted. In the Netherlands an assessment framework is available, but no actual CE-values are provided.

Evaluation of the cost-effectiveness of the proposed restriction

Figure 5-1 shows the calculated CE of the proposed restriction based on VOC.Since a benchmark range for VOC is not available and . This is given as a range based on the minimum and maximum case. The benchmark ranges discussed above are plotted in the same graph. Here, the ranges reflect the ‘assessment range’ as described above.

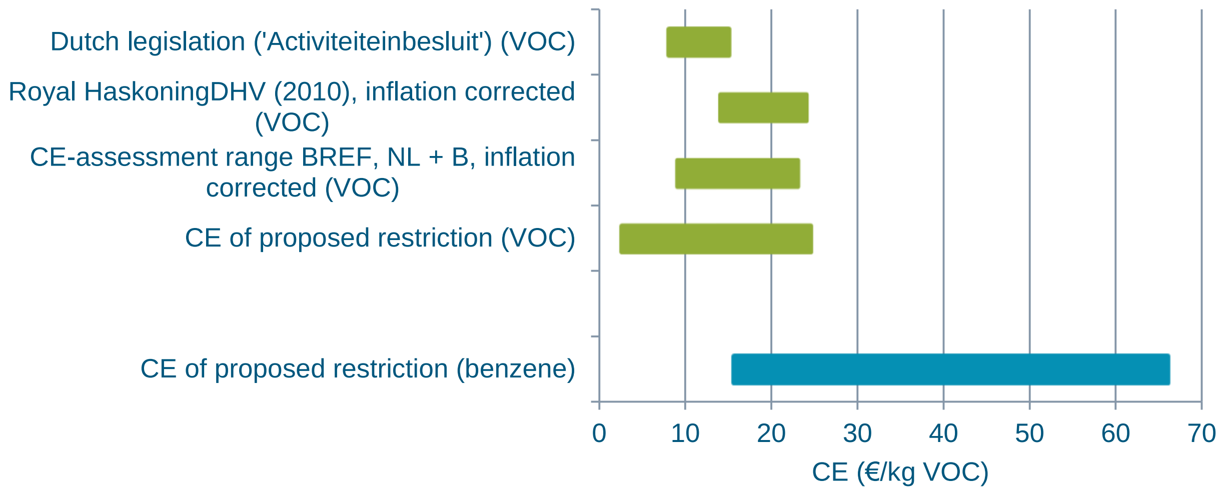


Figure 5-1: CE of proposed restriction (based on minimum and maximum case for VOC) and benchmark CE-ranges (‘assessment range’)

Considered as VOC emission reduction

When we consider the cost-effectiveness of the proposed restriction as a VOC emission reduction measure, the measure can be considered ‘possibly cost-effective’ since the average values of 15 € / kg VOC is in the assessment range applied for industrial VOC emission reduction measures. The maximum value of the CE-range for the restriction (25 € / kg) is above the upper limits of all benchmark cost effectiveness ranges. However, the maximum scenario, based on the transport of only the most volatile products within each of the UN-numbers is an extreme and unlikely case.

Considered as benzene emission reduction

When we consider the cost-effectiveness of the proposed restriction as a benzene emission reduction measure, a quantitative benchmark cost-effectiveness range is lacking. The CE-range of the proposed restriction for benzene (16 – 66 € / kg, average 41) is significantly higher than that of VOC. However, benzene is carcinogenic and mutagenic and higher abatement costs are generally accepted.

Conclusions on cost-effectiveness

Since the calculated CE-range for VOC is in the same order of magnitude as the benchmark assessment ranges, it is concluded that the cost of the proposed degassing restrictions for VOC are proportional. The higher CE of benzene can be accepted based on the carcinogenicity and mutagenicity of benzene.

6 Sensitivity analysis

In section 4.5, the impact of degassing restrictions is presented in the main output parameter of total cost for the supply chaing. This parameter depends on a number of input parameters. This section discusses the uncertainty of the input parameters and displays the sensitivity of the model to change of these parameters, or how changing parameters propagate to the main outcome.
The main outcome for this sensitivity analysis is defined as the total cost for the CDNI area in 2021, the first year when full restriction is in effect. To determine the sensitivity, the most prominent parameters are identified, a range of uncertainty is given, and the sensitivity of each of these is measured. Finally, the parameters are linked in four scenarios, displaying the impact of each scenario.

6.1 Input parameters

The first step in the sensitivity analysis is specifying the input parameters with significant uncertainty. Table 6-1 shows the direct input parameters of the model. The most right column provides an indication of relevance or priority for the sensitivity analysis. Relevance is determined based on impact and probability to change. The priority parameters are briefly discussed below.

Table 6-1: evaluation of input parameters and major assumptions

	Input parameter	Current value	Minimum value in Range	Maximum valu in Range	Priority for sensitivity analysis
	Number of degassings in 2014				
1	Accuracy IVS90 and extrapolation to CDNI	6560 degassings in CDNI	-20%	+20%	Yes
2	Compatibility in 2014	See text & table in section 2.3	*See text below*	*See text below*	Yes
	Number of degassings - predictions				
3	Reduction of required degassings due to market optimization, as percentage of total necessary degassings	60%	80%	20%	Yes
4	Market growth, per annum	2%	-	-	No
	Degassing installation				
5	Average required degassing time per degassing	8 h	-25%	+25%	Yes
7	Utilisation rate degassing installation	60%	90%	50%	Yes
8	Average extra km to reach degassing installation	40km	-25%	+25%	Yes
9	Average cost for CAPEX + OPEX per annum	€ 1.350.000	-30%	+30%	Yes
	Other assumptions				
10	Assumption on transported product distribution in all countries	equal in all countries	-	-	No
11	(Fractional) implementation date	2019-2021	-	-	No
12	Percentage of UN1268 and UN3295 transports with > 10% benzene	40%	-	-	No

1. Accuracy IVS90 and extrapolation to CDNI

The estimation of the total necessary degassings is largely based on the records of the IVS90 database and extrapolation of this Dutch data to the CDNI area. The IVS90 database contains the recordings of inland shipping in the Netherlands: a measured given. As any measurement however, some uncertainty is involved due to missing or erroneous records. The Dutch IVS90 data is extrapolated to the other CDNI countries based on Eurostat data on shipped tonnages of goods by tanker barge per country, or specific regional information provided by the country (Germany and France). Based on IVS90, 3626 records are found requiring degassing in NL; multiplied with 181%, based on Eurostat, gives a total of 6560 degassings in the inlands of the CDNI region. A margin of ±20% is used in this analysis.

2. Compatibility in 2014

The current matrix implies a rather low compatibility of cargoes: as a succeeding cargo, only UN1267 and UN1268 are compatible with all, and UN1203, UN1223 and UN2398 are compatible with some. In total roughly 10% of the found transfers are thought to be compatible, not requiring degassing.
For the sensitivity analysis we look at the most sensitive transfers, being the cargo combinations that are most frequent. The table below lists the most frequent cargo changes, a list of 7 combinations covering 70% of the studied transfers.

Table 6-2: Most frequent cargo transfers

Preceeding Cargo	Succeeding Cargo	Frequency	Profile 0	**Profile 1**	**Profile 2**
1268	1202	30%	0%	**5%**	**10%**
1268	1203	10%	0%	**5%**	**10%**
1268	unknown	10%	0%	**5%**	**10%**
1268	3295	5%	0%	**75%**	**75%**
3295	1202	5%	0%	**5%**	**10%**
3295	1268	5%	75%	**75%**	**75%**
3295	Unknown	5%	0%	**5%**	**10%**

The table shows three profiles: profile 0 (based on assumptions supported in section 2.3), profile 1 and profile 2. Profile 1 results in 14% of the found transfers being compatible, not requiring degassing. For profile 2 this is 17%. The model works with these three given profiles.

3. Reduction of required degassings due to market optimization, as percentage of total necessary degassings

The further decrease of necessary degassings, given as a fixed percentage of the business as usual scenario, is due to market response, including e.g. dedicated transport and increased compatibility. The given 60% in the current scenario implies that 60% of required degassings is eliminated by market response. The Excel model has the option to vary percentages over the different UN-numbers. This sensitivity analysis calculates with a single value for all UN-numbers.
An estimation of maximum market response is 80%, resulting in minimum number of required degassings.
An estimation of minimum market response is 20%, resulting in maximum number of required degassings.

4. Average required time for degassing

The average required time per degassing is estimated at 8h. It should be noted that time shows to be a great denominator. Today, controlled degassing takes place using the piping infrastructure on the barges (as these itself need to be degassed).

This on-board infrastructure generally forms a bottleneck in increasing the speed of gas flow. Since time is known to be a costly factor, developments in speeding up the degassing process are to be expected. For example, the initial vapour concentration can be reduced by washing. The model works with a range of ±25%.

5. Utilisation rate degassing installation

The utilisation rate, together with the average time for degassing, determines the number of vessels to be degassed by an installation. The current model is based on a utilisation of 60%. A maximum utilisation is estimated at 80%, and a minimum utilisation at 20%.

6. Average extra km to reach degassing installation

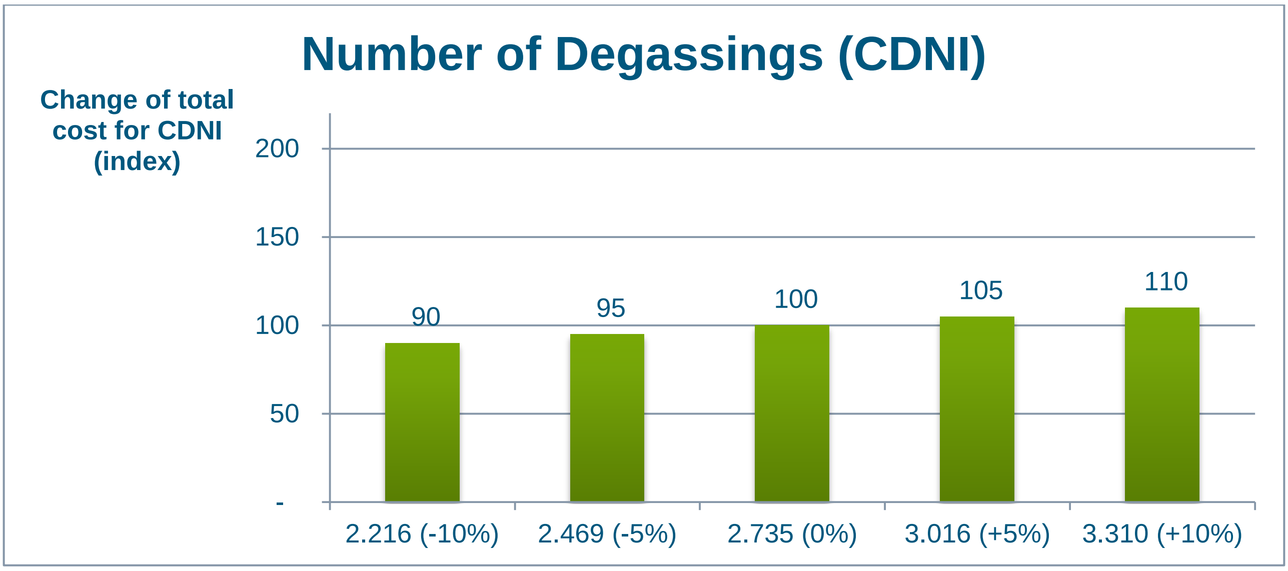
The degassing installations are projected to be separate installations – not linked to terminals. On average, barges are therefore expected to make a detour to reach a degassing installation. An average distance of 40km is used as initial input. There may be reasons however for barges to take more or less time reaching an installation, such as transition phase (when there are less than 5 installations), unequal spreading of installations or growth of population of installation (resulting in more than 5 installations). An average maximum detour is estimated at 60km, and a minimum at 20km.

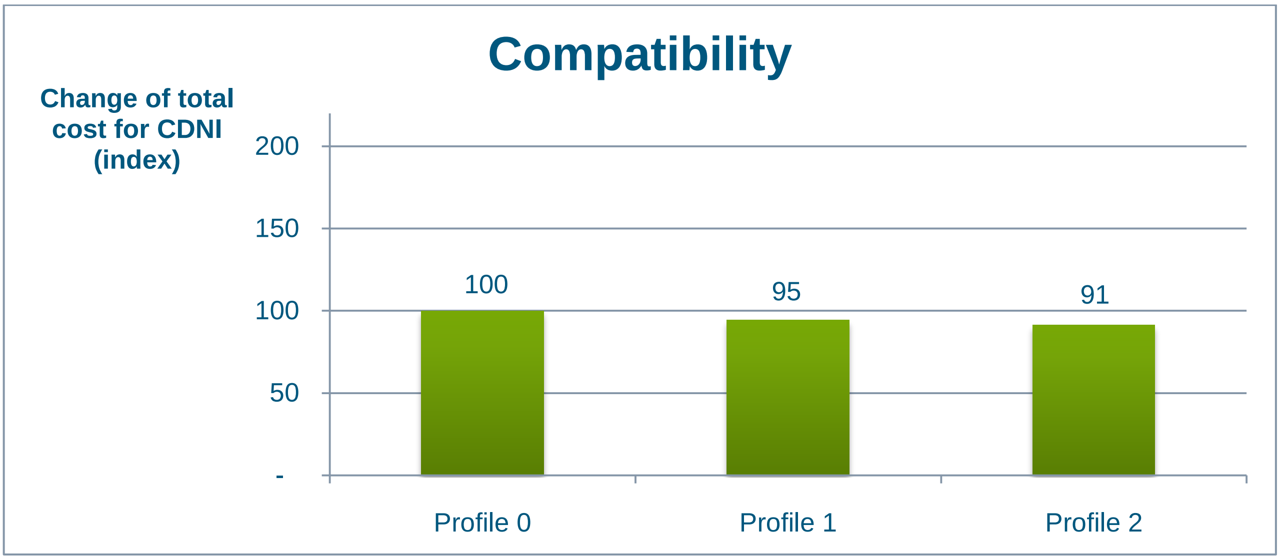
7. Average annual cost for CAPEX + OPEX

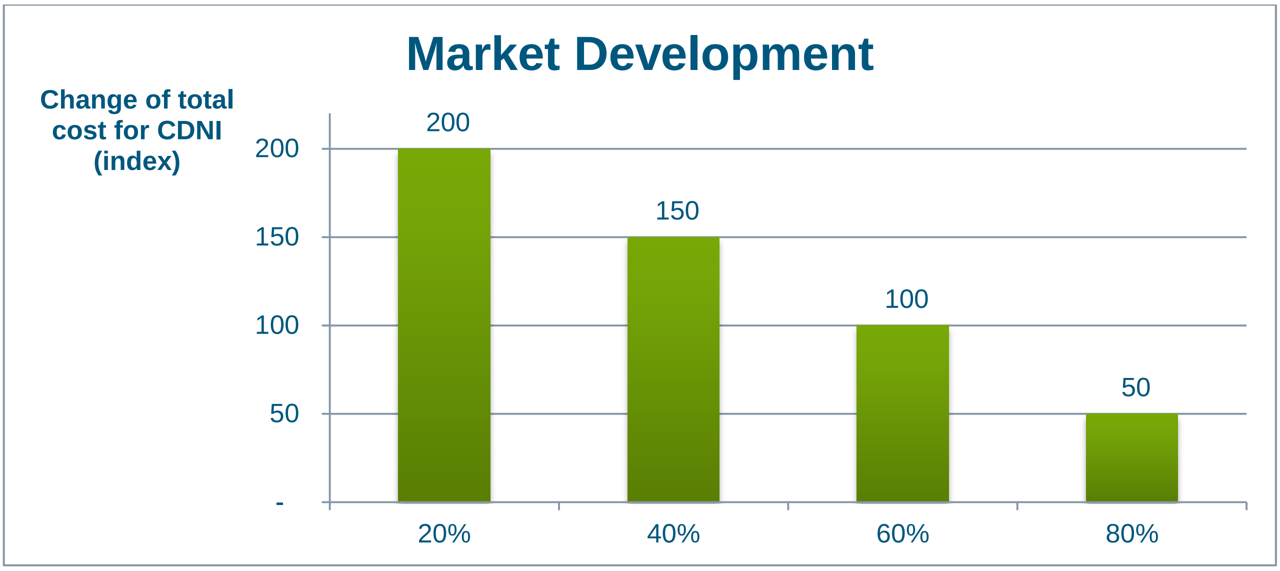
Large influencers for CAPEX include equipment costs (technology for equipment is still highly under development) and initial presence of berthing facility. Large influencers for OPEX include energy prices and the utilization rate of the installation. The current model works with an annual cost for CAPEX and OPEX of roughly €1.350.000. This sensitivity analysis works with a range of ±30%.

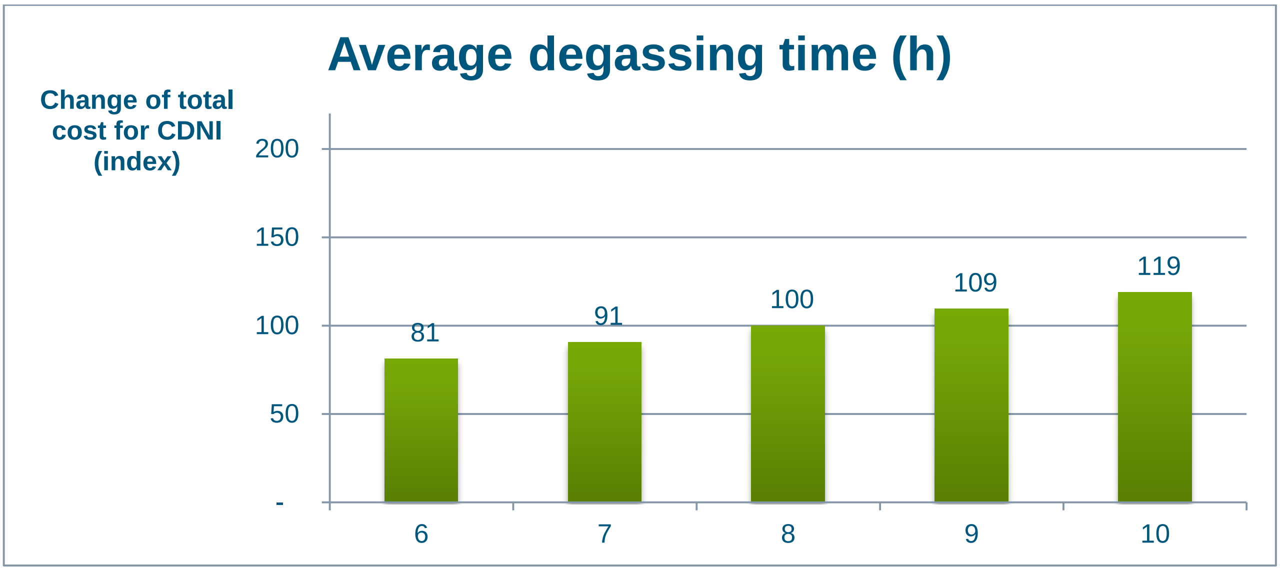
6.2 Sensitivity by single input parameter

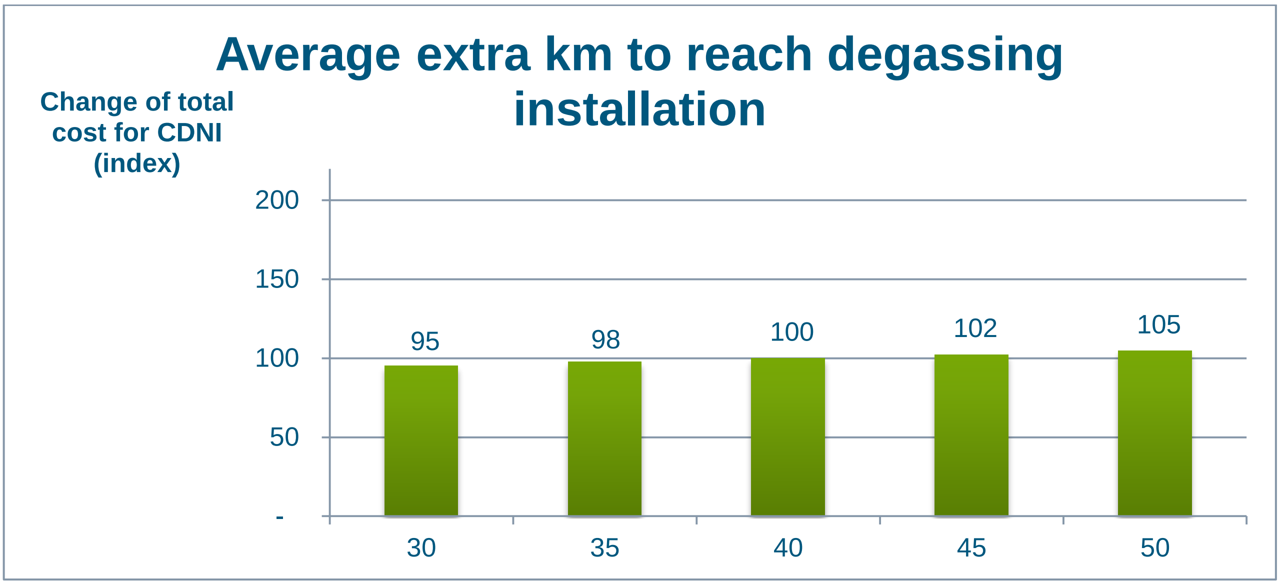
The effect of changing each of the given parameter is plotted in the following graphs. The graphs show indexed change of the total cost for CDNI area in 2021, when the full restriction is expected to be in effect. Each graph includes a column without change (index=100, being the OMD scenario as outlined in previous sections) and a relevant number of additional columns, depending on the parameter.

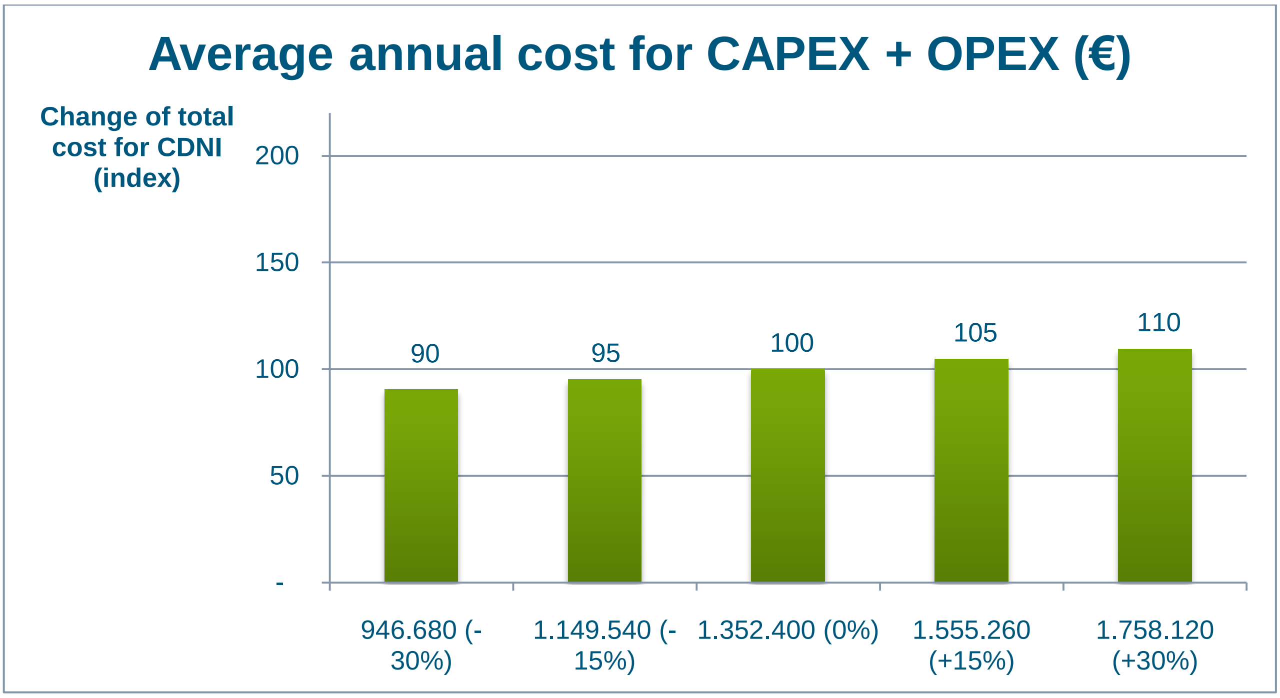


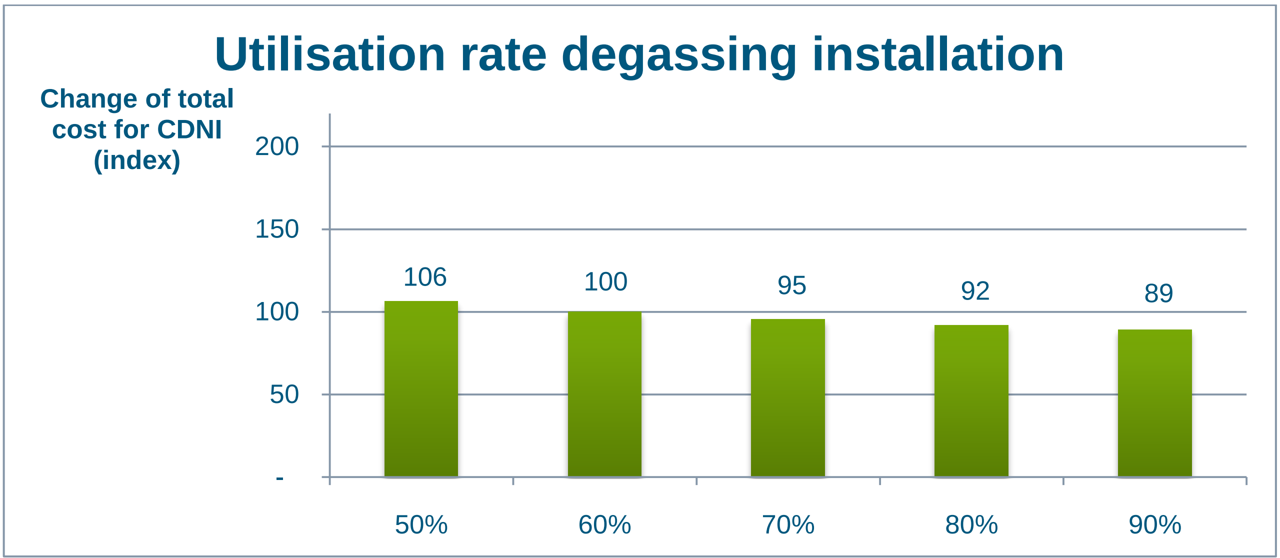

Compatibility
Change of total cost for CDNI (index)
200
150
100
50
-
100
95
91
Profile 0
Profile 1
Profile 2


Market Development
Change of total cost for CDNI (index)
200
150
100
50
-
200
150
100
50
20%
40%
60%
80%


Average degassing time (h)
Change of total cost for CDNI (index)
200
150
100
50
-
81
91
100
109
119
6
7
8
9
10


Average extra km to reach degassing installation
Change of total cost for CDNI (index)
200
150
100
50
-
95
98
100
102
105
30
35
40
45
50


Average annual cost for CAPEX + OPEX (€)
Change of total cost for CDNI (index)
200
150
100
50
-
90
95
100
105
110
946.680 (-30%)
1.149.540 (-15%)
1.352.400 (0%)
1.555.260 (+15%)
1.758.120 (+30%)



6.2.1 Conclusion

The largest diversion in impact is seen at the parameter Market Development, followed by the Average Degassing Time. The parameter Market Development also shows the largest diversion in input variance, partially explaining the great diversion in impact.

6.3 Scenarios

The impact of the given parameters changing at once is estimated using scenarios. Considering potential changes on macro-level, a scenario provides cohesive estimates for all parameters. Four scenarios are identified and elaborated below. The scenarios include a scenario 0, a best guess based on the Optimal Market Development (OMD) scenario outlined in the previous sections, and three additional scenarios:

- Scenario 0: Best Guess;
- Scenario 1: Degassers Market;
- Scenario 2: Innovation in all Markets;
- Scenario 3: No Attention.

Scenario 0: Best Guess
This scenario is the OMD scenario as outlined in previous sections: a best guess based on expert judgement. Table 6-3 lists the values for the input parameters.

Scenario 1: Degassers Market
A scenario is plotted where a lot of degassing takes place, however the product owners / barges are not moving (to decrease the need for deassing) and no need is felt to innovate the degassing process itself. This scenario shows a maximum number of degassings from the IVS database, little compatibility and minimal market development. The degassing process is assumed to be equal to scenario 0, with little higher CAPEX and OPEX, as the owner of a degassing installation is not thought to seek any form of optimization. Extra distance is expected to decrease to a minimum, as more installations will pop-up in this attractive market for degassers. Table 6-3lists the values for the input parameters.

Scenario 2: Innovation in all markets
A scenario is plotted where both the product owners / barges and the owners of degassing installations are moving. This scenario shows no change in the accuracy for IVS90 and CDNI data, but maximum compatibility and market development. Moreover, the degassing process is assumed to be optimized, resulting in maximally decreased degassing time, maximum utilization rate, a little less extra km to reach installation (flexible constructions would allow for more, smaller installations) and a little less cost for CAPEX and OPEX. Table 6-3lists the values for the input parameters.

Scenario 3: No attention
In this scenario the subject of degassing is not given much attention from neither the product owners / barges nor the owners of degassing installations. It starts with a smaller initial number of degassings. No change is expected in compatibility, and market development is thought to be slightly less than in scenario 0. Degassing installations are not expected to change much: degassing time and cost for CAPEX and OPEX is not expected to change; with the low attention less installations are expected, resulting in larger distance to reach the installation, and slightly reduced utilization rate. Table 6-3 lists the values for the input parameters.

Table 6-3: Summary of parameter values in the given scenarios

	Input parameter	Value Scenario 0	Value Scenario 1	Value Scenario 2	Value Scenario 3
	Number of degassings in 2014				
1	Accuracy IVS90 and extrapolation to CDNI	**6.560**	*+10%*	*No change*	*-10%*
2	Compatibility in 2014	**Profile 0**	*No change*	**Profile 2**	*No change*
	Number of degassings - predictions				
3	Reduction of required degassings due to market optimization, as percentage of total necessary degassings	**60%**	**20%**	**80%**	**40%**
	Degassing installation				
5	Average required degassing time per degassing	**8h**	**8h**	**6h**	**8h**
7	Utilisation rate degassing installation	**60%**	**80%**	**90%**	**50%**
8	Average extra km to reach degassing installation	**40km**	**30km**	**35km**	**45km**
9	Average annual cost for CAPEX + OPEX	**€ 1.350.000**	*+15%*	*-15%*	*No change*

Legend:
Absolute value
Relative value to Scenario 0

6.4 Impact of scenarios

Figure 6-1 shows the impact of the three scenarios indexed to scenario 0, best guess, measured by the total cost for CDNI in 2021 (when the full restriction is suggested to be in effect).

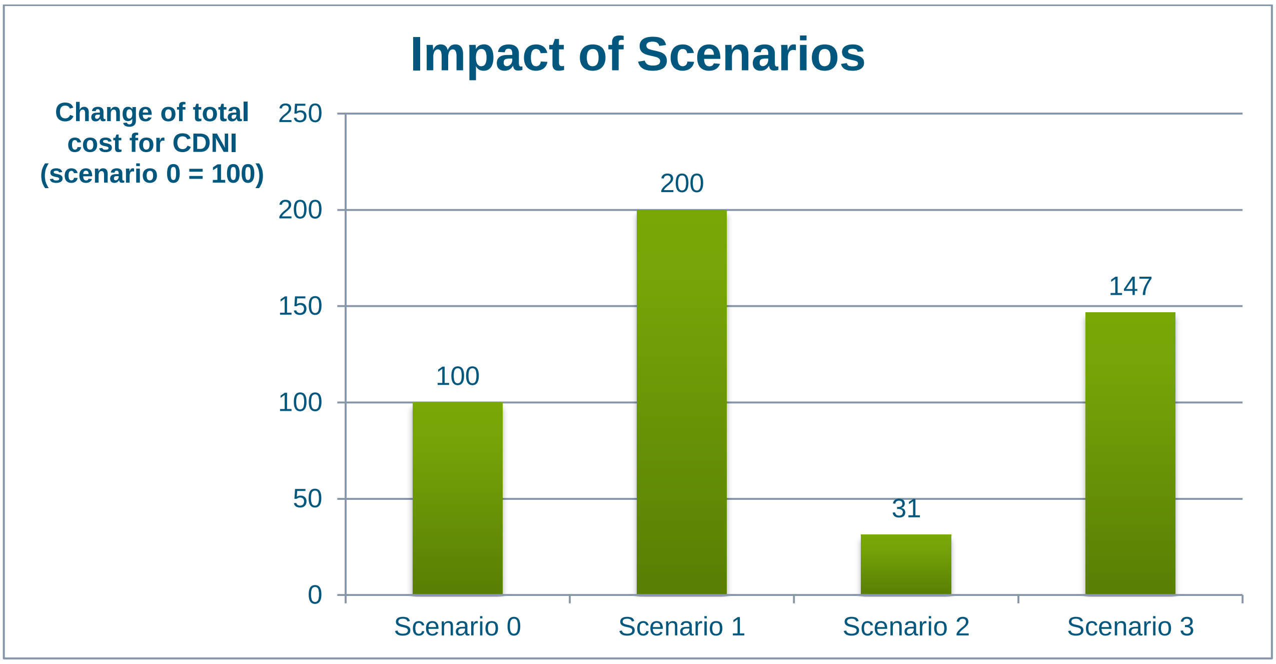


Figure 6-1: Impact of scenarios on the total cost for CDNI in 2021

A first thing to notice is the large variance: index numbers as high as 200 and as low as ~30 are shown. Important to account for is the role of the parameter Market Development.

The index number for scenario 1 corresponds with the output of the single parameter of Market Development whenusing the same entry value for this parameter. A check on scenario 1 shows that indeed, when Market Development is set at 60% as in scenario 0, the percentual difference is minimal (index = ~100). The same goes for scenario 3.
In Scenario 2, the largest impacting factors are again Market Development, accounting for the reduction of ~50%, followed by the time needed for degassing, accounting for another ~20%.

The scenarios show that a great variance is thought to be possible. It is noted that this large variance is mainly caused by the parameter Market Development.

7 Conclusion & discussion

Phased incorporation in CDNI

To incorporate degassing restrictions in the CDNI treaty, we recommend a phased introduction. This phasing is based on starting with those products most harmful for humans and the environment and the largest actual transported volumes. We propose the following phasing on basis of the seven products included in this impact assessment:

2019: UN1114 – UN1267 – UN1268 (> 10% benzene) – UN1863 – UN1993 – UN3295 (> 10% benzene) – UN3475

2021: UN1268 (< 10% benzene) – UN3295 (< 10% benzene)

Other Top-25 products can be included in the second phase in 2021.

Expected market response

To allow the inland tanker transport sector to anticipate on this restriction, facilities for controlled degassing are needed. We know that part of the degassings that currently take place will be avoided when degassing to the atmosphere is prohibited. This will be realized by several market optimization mechanisms, including dedicated transport. In this impact assessment, we applied a 60% reduction of the number of current degassing due to these market optimization mechanisms. We call this the Optimal Market Development (OMD) scenario. This is based on our experience and discussion with various stakeholders. Though we recognize the market behaviour is hard to predict, we also see that the magnitude of this market optimization is very important in the assessment of the impact on the supply chain. Gaining more insight in the expected market response would therefore be valuable.

Part of the uncertainty in the expected market response is due to a lack of understanding of compatibility of products. A better understanding of compatibility is an important first step in the development of a better market optimization assessment.

Finally, we expect that solutions will be found to decrease the time needed for degassing. This will also impact the number of installations and the total cost of degassing significantly.

Degassings, installations and costs

Based on the OMD scenario (that includes also a 2% growth in transported volumes) and the phased introduction described above, we foresee a need for about 1,300 controlled degassings per year in 2019 and 2020 and 2,700 – 3,000 per year in the period 2021 – 2025. On basis of about 700 degassings per year per installation, this can be realized with 2 installations in 2019 and 2020 and 4 – 5 installations in the period 2021 – 2025. The total cost for the supply chain in these two periods range between 8 and 20 million Euro per year.

We believe it will be necessary to have 5 installations available from 2019 on (instead of 2 based on number only), since the large distance between installations will result in unacceptable additional sailing time to travel to the nearest degassing installations.. As a consequence, the cost effectiveness of the installations might not be optimal in the first two years of operation due to an operation below the design capacity. A further quantification of this effect in relation to the phasing, including the analysis of flexibility in capacity of installations, is recommended.

The cost-effectiveness of the proposed restrictions ranges from 3 to 25 €/kg avoided VOC emission and 16 to 66 €/kg avoided benzene emission. Since this range for VOC is in the same order of magnitude as the benchmark assessment ranges, it is concluded that the cost of the proposed degassing restrictions for VOC are proportional. The higher CE of benzene can be accepted based on the carcinogenicity and mutagenicity of benzene.

Sensitivity analysis
There is a significant uncertainty in the input parameters. This propagates to the main outcomes. The largest diversion in impact is seen at the parameter Market Development (partly caused by the largest diversion in input variance), followed by the Average Degassing Time. Four scenarios, based on cohesive estimates for all parameters, show that a great variance is thought to be possible. This is mainly caused by the parameter Market Development.

Appendix

1. Literature

Royal HaskoningDHV

1 Terms of Reference for the Development of Guidelines for the Handling of Gaseous Residues of Liquid Cargo transported by Inland Tanker Shipping (GRTS), 9 July 2013

2 Rabobank, *Cijfers & Trends – Binnenvaart*, 21 November 2015

3 Centrale Commissie voor de Rijnvaart (CCR), *Analyse en evaluatie van structurele markttrends in de binnenvaart*, juni 2013

4 CCR, Europese Commissie, Panteia, *Europese binnenvaart – Marktobservatie 2014*, september 2014

5 ING Economisch bureau, *Binnentankvaart verliest koers*, juni 2015

6 Royal HaskoningDHV, *Vent Free Level – When is an inland tank barge free to vent?*, 2015

7 Port of Rotterdam, *Feasibility study: Sustainable degassing of barges*, B.Sc. thesis by Stef Blok, Hogeschool Rotterdam, June 11th 2014

8 Royal HaskoningDHV, *Ontgassen van binnenvaartschepen in de Rotterdamse haven – Een verkenning van mogelijkheden en kosten*, 27 September 2013

9 Royal HaskoningDHV, *Review of techniques for degassing barges*, assigned by Cefic and CONCAWE, 30 September 2013

10 Royal HaskoningDHV, confidential source, 2012

11 Royal HaskoningDHV, *Recover C - Resource efficient inland liquid bulk transport*, september 2015

12 Rijkswaterstaat Dienst verkeer en Scheepvaart, *Memo Indexering Kostenkengetallen binnenvaart 2011*, 13 February 2012

13 BiPRO GmbH, Machbarkeitsstudie zur Einrichtung und zum Betrieb von Abgasreinigungsanlagen für die Nutzung durch Tankschiffe im deutschen Teil des Rheinstromgebietes, assigned by the Umweltbundesamt, July 2014

14 Stuctuurvisie Infrastructuur en Ruimte, Ministerie van Infrastuctuur en Milieu

15 CE Delft, *Update emissions degassing inland tank vessels*, assigned by VNPI, November 2013

16 EFOA, *MTBE / ETBE Transport over inland waterways*, March 2008

17 *Report GRTS to CDNI/G*, Maurits Prinssen, Chairman of the GRTS SC, 25 February 2015

18 RWS, *kegelligplaatsen,* excel spreadsheet received in November 2015

19 Periskal, *Rhine Area*, http://www.periskal.com/nl/binnenvaart/producten/kaartzones/kaartzones

20 RWS, *Indexering Kostenkengetallen Binnenvaart 2011*, February 2012

21 GRTS, Top-25 Transported Products

22 CE Delft, *Ontgassen van lichters*, Commissioned by VNPI, VOTOB and AVV, December 2003

23 API, *Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations*, API 2524A, second edition, September 1981, reaffirmed March 2001.

24 AEA Technology, Measures to reduce emissions of VOC's during loading and unloading of ships in the E.U., August 2001

25 RIVM, Diffuse emissies en emissies bij op- en overslag – Handboek emissiefactoren, maart 2004

26 Royal HaskoningDHV, Vent Free Level – When is an inland tank vessel free to vent?, 2015

27 European Commission, Integrated Pollution Prevention and Control Reference document (BREF) – Economics and Cross-Media Effects, July 2006

Royal HaskoningDHV

28 DHV, *Onderzoek kosteneffectiviteit in de NeR*, assigned by the Dutch Ministry of the environment (VROM), April 20th 2010

Appendix

2. Compatability Matrix from literature

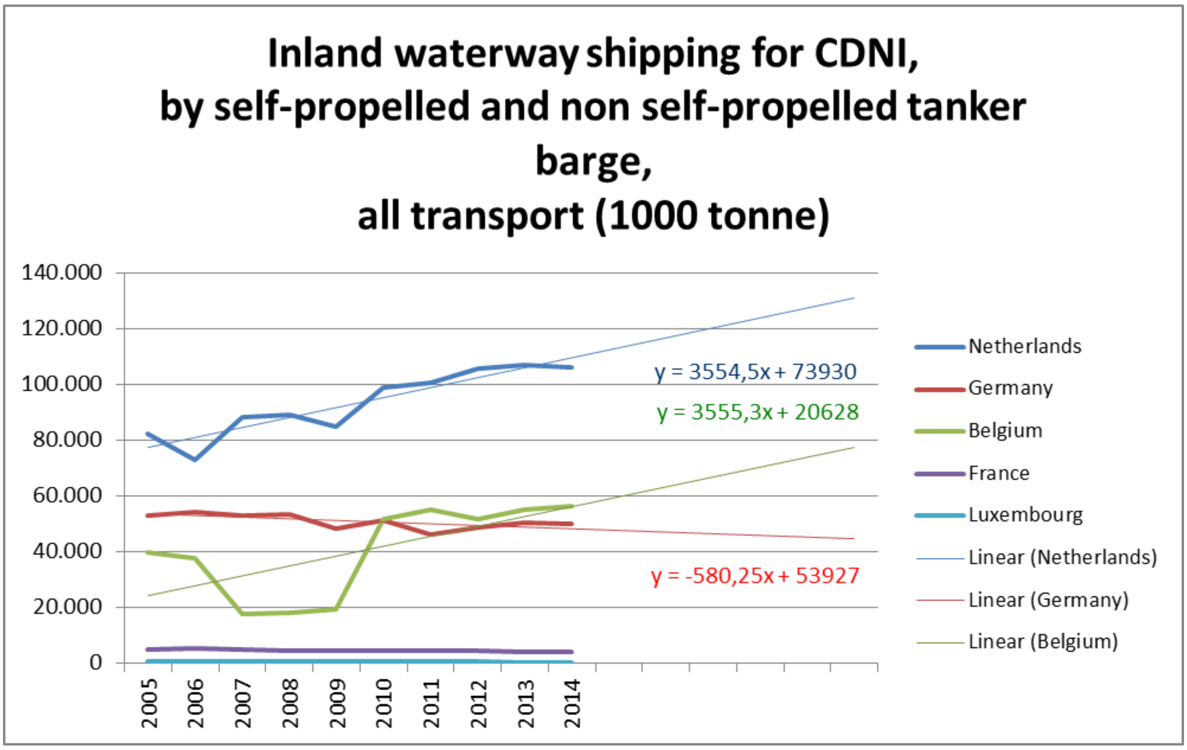
Royal HaskoningDHV

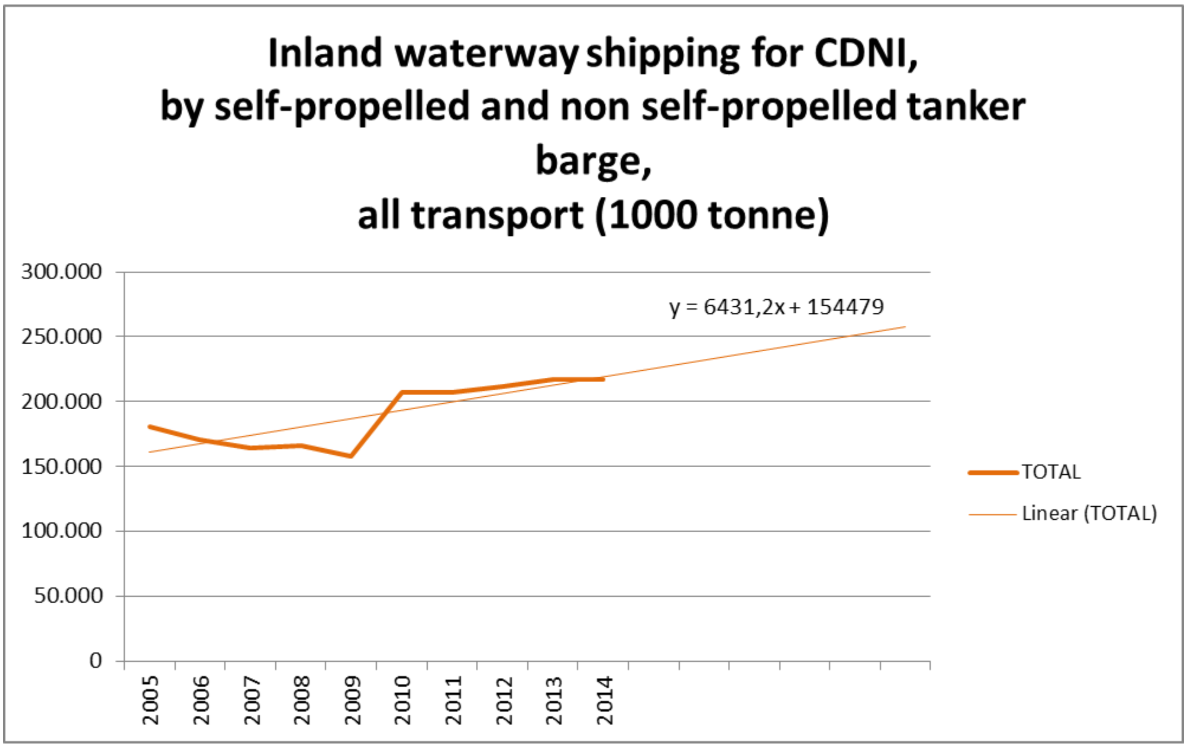
		Heating oil dyed	Heating oil undyed	Diesel dyed	Diesel undyed	Jet A1	AVGAS 100LL	Petroleum (burning kerosene)	Petrol	Naphtha as gasoline bleding components	FAME
Heating oil dyed	UN1202										
Heating oil undyed	UN1202										
Diesel dyed	UN1202										
Diesel undyed	UN1202										
Jet A1	UN1863										
AVGAS 100LL	UN1863										
Petroleum (burning kerosene)	UN1223										
Petrol	UN1203										
Naphtha as gasoline bleding components	UN1268										
FAME	UN1202										

Compatibility matrix, reconstructed from [15] and [16]

Appendix

3. Inland Waterway Shipping for CDNI Countries


Inland waterway shipping for CDNI,
by self-propelled and non self-propelled tanker barge,
all transport (1000 tonne)
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
y = 3554,5x + 73930
y = 3555,3x + 20628
y = -580,25x + 53927
Netherlands
Germany
Belgium
France
Luxembourg
Linear (Netherlands)
Linear (Germany)
Linear (Belgium)

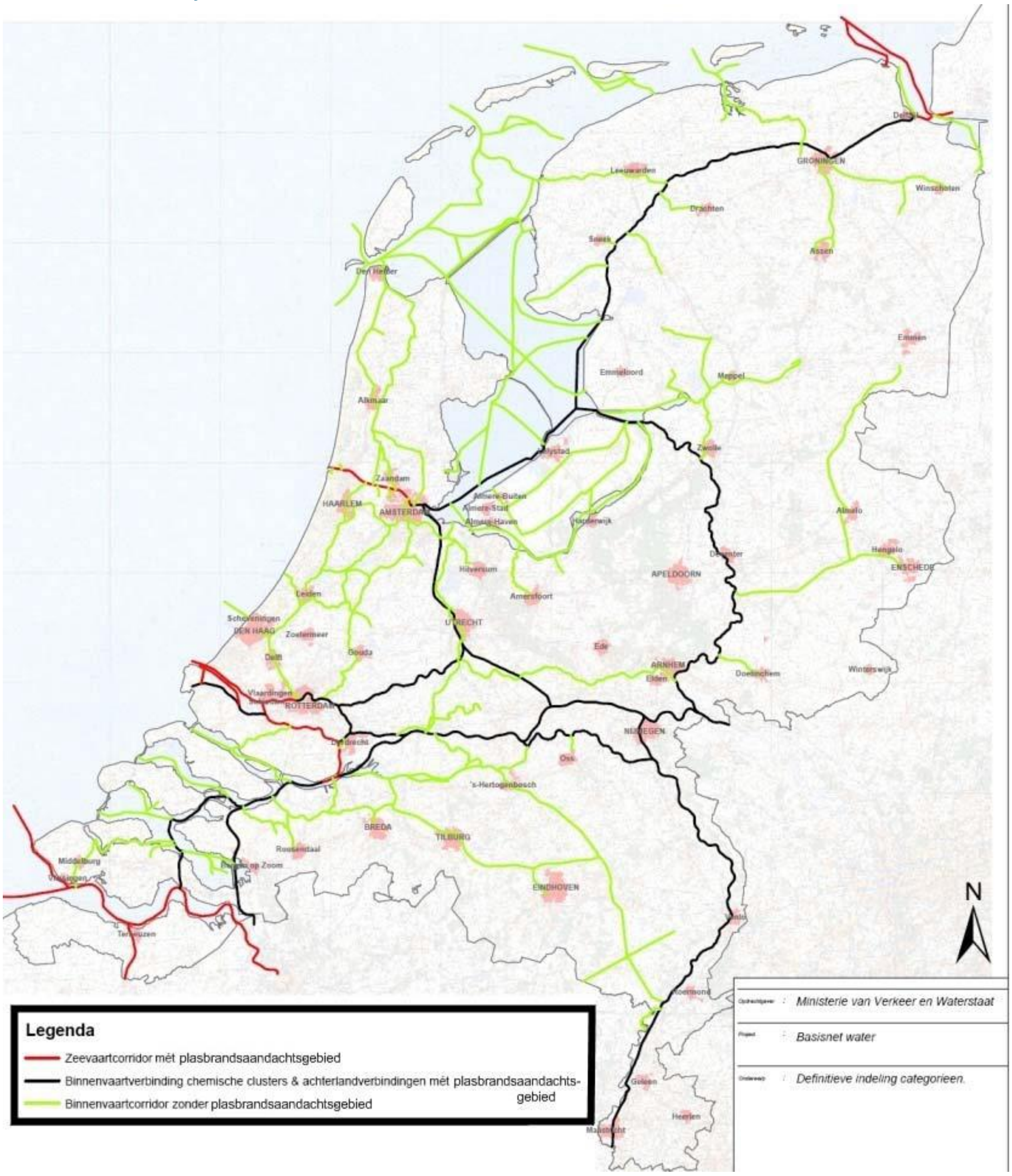

Inland waterway shipping for CDNI,
by self-propelled and non self-propelled tanker barge,
all transport (1000 tonne)
300.000
250.000
200.000
150.000
100.000
50.000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
y = 6431,2x + 154479
TOTAL
Linear (TOTAL)

Appendix

4. Detailed Waterways CDNI

Royal HaskoningDHV

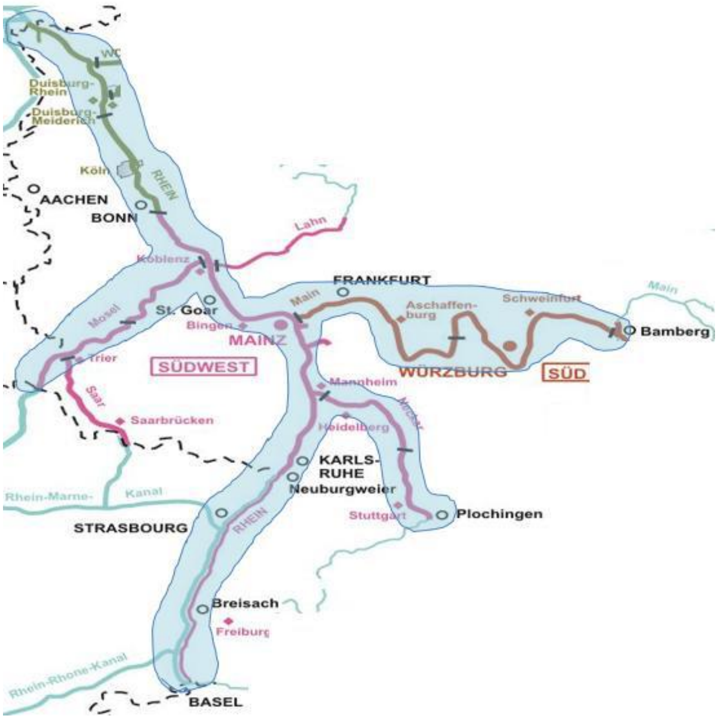
Detailed waterways in the Netherlands



Detailed waterways in Belgium

http://www.binnenvaart.be/nl/waterwegen/kaarten/index.html

Detailed waterways in Germany (Rhine area)



BIPRO, 2014

Appendix

5. Detailed Costs Berthing Facility

A5 Detailed Costs Berthing Facility

A5.1 Introduction

Within the framework of the planned limitation of degassing within the framework of the CDNI convention it is anticipated to realise facilities for inland tanker barges to degas in a controlled way.
This note by Royal HaskoningDHV (drafted by Ruud Roelfsema) describes the required facilities and provides a global estimate for the investment costs.

A5.2 Description of facilities

Starting points:

- Facility is located in the port of Rotterdam
- Facility is situated parallel to the shore
- The shore is a slope, see sketch in Attachment A
- No dredging
- Length of barges vary from 38,70m to 135m
- Maximum draft 4.40m
- Under keel clearance 1m with rock bottom
- LLWS NAP – 1.50m
- Minimum level of water bottom -1.5-1-4.4 = NAP – 6.90m
- Maximum design vessel: super bunker tanker “Vlissingen”, 9,000 ton, see Attachment B
- Minimum design vessel: Spits 38,70 X 5,05 X 2,20m, gem. 364 ton
- Vessels use bow trusters
- Discharging via connection with loading arm or hose tower
- Platform to facilitate installation of loading arm/hose tower, accompanying piping and firefighting equipment
- Access trestle between shore and platform for installation of piping and walk way for pedestrians
- Escape routes from vessel to shore

A5.2.1 Berthing structure

In order to berth the wide range of vessels and fasten the mooring lines it is proposed to apply a steel continuous berthing structure in front of the platform. This structure also protects the platform from impact of berthing vessels.
The berthing structure is separated from the platform to allow for the deflection which is required to absorb the berthing energy.

The primary structural components are steel vertical tubular piles interconnected by a longitudinal tubular beam. The tubular beam is provided with vertical members for connection of the fender beams, ladders, bollards and a walkway on top of the berthing structure.

On the berthing structure vertical ladders need to be installed to provide access to the walkway on top of the berthing structure. In order to provide escape routes for a wide range of vessels quite a lot of ladders are needed.
It is recommended to choose the top level of the berthing structures at NAP +7 m, because the design vessel of 135 m will have a considerable freeboard (approx. 5.15m), with high tide the level of the deck is approx. NAP + 7m. In that situation it must be able to enter the walkway on top of the berthing structure.

A5.2.2 Catwalks

For safety reasons escape routes from the vessel must be provided in case of emergency.
Therefore at both ends of the berthing structure a walkway to the shore is provided. Access from the walkway to the platform is possible as well. These walkways will be of a so called catwalk type. This is a common maritime construction for which various design solutions and unit rates are available. This is the reason why details of the catwalks are not provided in this note.

A5.2.3 Platform

The dimensions of the platform depend on the number/size of loading arms/ hose tower it is anticipated to adopt a surface of 100 m2.
The platform is composed of a concrete deck on concrete piles. A beam grid will be created on which prefabricated concrete slabs will be installed with an in situ concrete compressive layer.

A5.2.4 Access trestle

The structure consists of vertical steel tubular piles and a large horizontal longitudinal tube. On the longitudinal tube cross beams are created every 5 m.
On one side of het trestle a walkway will be created for access to the platform by foot and bicycle only and for inspection of the pipelines. The walkway consists of a grating supported by longitudinal girders. The other side is available for the pipe rack.

A5.2.5 Scour protection

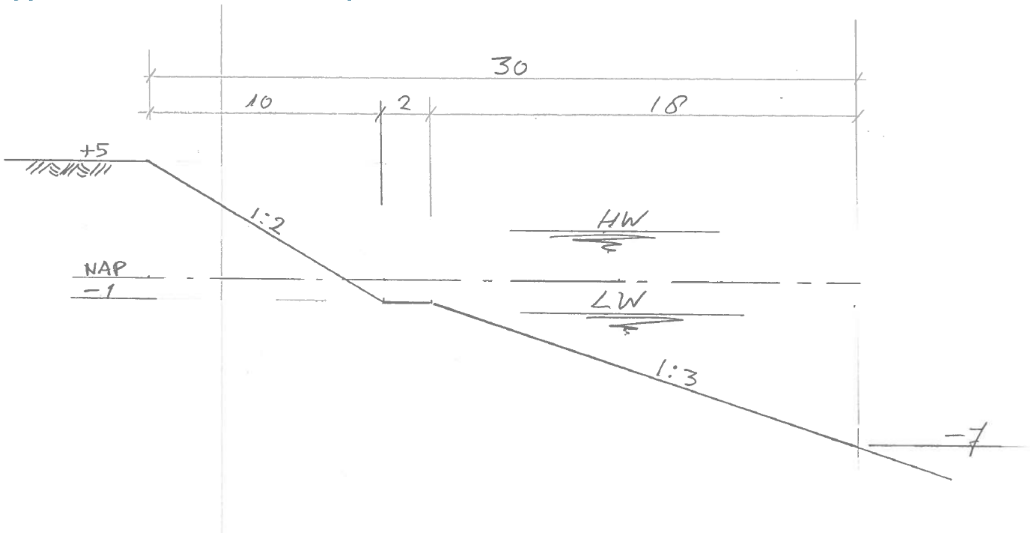
The vessels will be berthed close to the slope. The manoeuvring process and departure of vessels will result in propeller induced currents. The velocities will be very high and can cause erosion of a sandy water bottom. In order to prevent instability of the shore it is necessary to protect the slope and the toe of the slope from erosion. It is anticipated to apply a scour protection of 10 – 60 kg rock, installed on a geotextile and penetrated with colloidal concrete.

A5.3 Costs

The total investment costs are estimated at Euro1.8 million excl. VAT.
The accuracy of this estimate is + or – 30%.
Price level Q4 2015.

A substantiating of this cost estimate is provided below.

Typical cross section of slope



Cost estimate (exclusive of VAT.)

Item		unit	quantity	unit rate	cost
2.1	Berthing structure	m	120	€ 5.000	€ 600.000
2.2	Catwalks 2 no.	m	60	€ 1.500	€ 90.000
2.3	Platform	m2	100	€ 1.000	€ 100.000
2.4	Access trestle	m	20	€ 3.000	€ 60.000
2.5	Scourprotection	m2	2250	€ 50	€ 112.500
	Named direct construction costs				€ 962.500
	To be detailed	10%			€ 96.250
	Direct construction costs				€ 1.058.750
	Indirect construction costs	19%			€ 201.163
	Expected construction costs				€ 1.259.913
	Not appointed object related risks	10%			€ 125.991
	Construction costs				€ 1.385.904
	Engineering & site supervision	13%			€ 180.167
	Tax, fees and permits	2%			€ 27.718
	Insurances	1%			€ 13.859
	Investigations	2,50%			€ 34.648
	Sub total investment costs				€ 1.642.296
	Not appointed risks	10%			€ 164.230
	Totalinvestment costs				€ 1.806.526
	Total Investment cost (rounded)				**€ 1.800.000**