The impact of the ballast water management convention on shipowners and banks. The NIBC case

Master thesis:
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Preface

With this thesis, all requirements for my graduation in the MSc program Marine Engineering, within the *"Design Production and Operation"* (DPO) track, at the Delft University of Technology are met. The SDPO track provides a solid basis for working in the industry as well as in research institutes. The track is offered by the faculty of Mechanical, Maritime and Materials Engineering" (3ME). This thesis is commissioned at NIBC bank N.V., Den Haag. In this research, the impact of the IMO Ballast water management convention for ship owners and banks is explored. This report is intended for NIBC bank and maritime companies who are interested in installing a ballast water treatment system. Hence, it is assumed that the reader has basic understanding of shipping and its associated terminology.

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Acknowledgements

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I would also like to acknowledge all representatives of the classification bureaus, ballast water treatment manufacturers, ship owners, flag states, BWT consulting companies and my colleagues from NIBC, for helping me gathering data and exchanging information. All the interviews I had really helped me with my research. Without their enthusiastic and supportive input the research could not have been successfully conducted.

Finally, I want to express my gratitude to my parents and sisters for all their support throughout my study and research. This result could not have happened without them.

Summary

Ballast water, routinely taken on by ships for stability and structural integrity can contain thousands of microbes, algae and animals. When discharging this ballast water holding these organisms in a non-native ecosystem, new invasive aquatic species can be introduced. This can have to devastating consequences for the local ecosystem. To prevent further disruption of different ecosystems across the globe, the Ballast Water Management Convention (BWM) was adopted by the IMO in 2004.

NIBC has a wide portfolio of vessels which will have to comply with the IMO BWM convention. However, the possible solutions and the actual impact of this regulation is still unknown to the bank. Ship owners expect a significant impact on the shipping industry and it is suggested that a lot of vessels will have to be scrapped due to the high investment cost.

This research is conducted for ship owners and banks and will reveal the actual impact of the BWM convention. This is realised by calculating the impact on the internal rate of return (IRR) for each specific vessel. It provides the bank with a tool to monitor what effect the BWM convention will have on their clients. In addition, the tool is able to identify high risk vessels with an internal rate of return below 9%.

Ballast water treatment convention

The ballast water treatment convention was adopted in 2004 and will enter into force on the 8th of September 2017. This long foreseen regulation encouraged manufacturers to develop ballast water treatment systems, which are designed to be installed on new and existing vessels. As from July 2017 the IMO approved 69 different ballast water treatment systems.

Ballast water treatment methods and parameters

The ship owner aims to determine which ballast water treatment system needs to be installed on the vessel. The utmost important parameters for choosing a ballast water treatment system are the ballast water pump capacity and the sailing profile of the vessel. The ballast water treatment capacity has to be sufficient for the ballast water pump capacity. When these do not match, the speed of the loading and unloading of the vessel could be affected. The sailing profile is important for multiple reasons. It determines the water properties and the regulations that need to be followed in the areas in which the vessel is sailing. For systems using UV treatment, the UV transmittance of the water causes a restriction. When a vessel constantly sails in waters with low UV transmittance, the electrochlorination system may be a better solution. For systems using electrochlorination, the salinity is a restriction. If the vessel sails in fresh water only, it should consider an UV system instead.

Ballast water treatment systems

Two of the most commonly used ballast water treatment methods are UV treatment and electrochlorination. For large vessels carrying large volumes of ballast water, these two methods tend to become too voluminous when the ballast water pump capacity exceeds 3,000 m3/h. In these cases an inert gas system could be applied, which is independent from the ballast water pump capacity.

In this research 69 IMO approved BWT systems are analysed. It is expected that over time, less manufacturers will continue to manufacture these systems as certain systems will prevail over others. A total of ten ballast water treatment systems is selected based on performance and company background. It is important that the manufacturer has a good track-record and is globally represented to ensure sustainable and global service support. An overview of the different systems and the manufacturers is shown in table 1.

Treatment system	**Manufacturer**	**Treatment method**	**Capacity range (m3/h)**
PureBallast 3.1	Alfa Laval	Filtration + UV treatment	32 – 3,000
GLD BWTS	ColdHarbour	Inert gas	inf
Balpure	De Nora	Electrochlorination	500 - 20,000
RayClean	Desmi	Electrochlorination	300 – 3,000
Guardian	Hyde marine	Filtration + UV treatment	60 – 3,000
OBS	Optimarin	Filtration + UV treatment	167 – 3,000
GloEn-Patrol	Panasia	Filtration + UV treatment	1,000 - 3,000
Electro-cleen	Techcross	Electrochlorination	150 – 1,000
Aquarius UV	Wärtsilä	Filtration + UV treatment	50 – 1.000
Aquarius EC	Wärtsilä	Electrochlorination	750 – 3,300
Invasave300	Damen	Filtration + UV treatment	300

Table 1: Treatment systems with capacity ranges

Table 1 also shows the alternative Invasave300 solution, which is manufactured by Damen. This alternative system is manufactured for service providers to collect ballast water and treat it outside the vessel. The advantage of this system is the fact that the ship owner does not need to install a ballast water treatment system. This solution seems not suitable for the vessels of NIBC's portfolio since the capacity is still very limited and there is uncertainty whether all ports are able to provide this service. This treatment solution is considered more as an alternative option for smaller vessels or when the BWT system of a vessel malfunctions.

Cost study on ballast water treatment systems

A cost study on the purchase cost, installation cost and Opex is performed on the ballast water treatment systems mentioned in table 1, except for the alternative solution. This cost study shows no substantial price differences between the UV and EC systems for different ballast water pump capacities upto 3,000 m3/h. The inert gas system shows a significantly higher price. Nevertheless, it is capable of treating large amounts of ballast water with a relatively small footprint compared to the other methods.
The installation cost of a BWT system is very much dependent on the yard in which the installation is performed. Chinese yards quote installation costs that are just 22% of the quotes provided by European yards.
The yearly Opex of the systems range from $1,000 to $24,000 according to the cost study and are dependent on the capacity and treatment method. From this cost study it can also be concluded that the electrochlorination method only requires half of the power compared to an UV treatment method.
With this cost study, a range of prices can be given for each ballast water pump capacity. For the use of the tool, the two most extreme prices are left out to provide a representative price range. The second least expensive and second most expensive option is then used for the analysis by the tool. In the tool this is called a high-price and a low-price system. This represents a price range for which a ballast water treatment system could be purchased and installed, this can be seen as a sensitivity analysis. All the prices are based on quotations of ballast water treatment system manufacturers.

Strategies to follow

The implementation schedule of the IMO BWM convention leaves room for different strategies to follow in order to install a ballast water treatment system. In total, 23 different strategies are analysed of which only

Scenario	Description
Install a BWT system	This can be an IMO and/or USCG approved system
No BWT system is required	The vessel reaches the end of its assumed economic lifetime of 20 years, before a BWT system is required
Sell or Scrap	The vessel is to be sold or scrapped before the end of its lifetime
Use alternative BWT method	An alternative BWT method can be used without installing a system
No BWM convention	Hypothetical scenario used to calculate the impact of the BWM convention

Table 2: Different scenarios with short description

six are found to be feasible based on the assumptions made. The most important assumption is that the cost of a BWT system remains the same over time and that the lifetime of a vessel is 20 years. The strategies are grouped into four different scenarios. These four scenario's are shown in table 2. The fourth scenario which uses an alternative BWT method, like the Invasave300 manufactured by Damen, is not taken into account for this research. A hypothetical fifth scenario is added, which represents the old scenario without any BWM regulation. This hypothetical scenario is added in order to be able to calculate the impact of the BWM convention by comparing the forecasted outcome with this hypothetical scenario.
The six strategies that are feasible according to the assumptions made are:

- Strategy 2 (Installation of a BWT system during next dry-docking (first planned dry-dock after 8th of September 2017))
- Strategy 4 (Sell/scrap vessel before second dry-docking (first planned dry-dock before 8th of September 2017))
- Strategy 5 (Installation of a BWT system during second dry-docking (first planned dry-dock before 8th of September 2017))
- Strategy 16 (IOPP renewal, perform regular dry-docking and sell/scrap vessel before next IOPP renewal)
- Strategy 17 (IOPP renewal, perform regular dry-docking and install BWT before next IOPP renewal)
- Strategy 21 (Sell/scrap vessel before first dry-docking (first planned dry-dock after 8th of September 2017))

Tool description

A tool is created to find the best strategy for each vessel based on the internal rate of return. It also calculates the impact of the ballast water treatment system on the expected IRR. The IRR is a metric to measure the return on each dollar invested. The tool generates cash flow models for each strategy to compare. The strategy for each scenario with the highest forecasted IRR is then selected.

To make a comparison, a cash flow model of the vessel without the installation of a BWT system is created, this is the hypothetical scenario. The difference between this IRR and the highest IRR with the installation of a ballast water treatment system is considered as the impact of the ballast water management convention. Besides the IRR, the tool can calculate the maximum loan amount for which the ship owner is still able to pay debt service with the cash flow of the vessel. A cash-reserve, if available, can be added to this calculation.

The output of the tool is a database of the vessels in NIBC's portfolio with the expected IRR. The database contains IRR's of all different cases and scenarios and suggests which strategy to follow. The tool is created in such a way that quarterly available MSI [**?**] data can easily be updated. Also other assumptions, like a change in cash-reserve, or the going into-force date of the BWM regulation are easily adaptable. The tool is flexible, user-friendly and can be used for a wide range of applications for future use by the bank.

NIBC and world fleet analysis

The tool is used to analyse NIBC's portfolio and the world fleet. A general conclusion is that since a vessel-lifetime of 20 years is assumed, that vessels built before 2003 will not be impacted by the BWM convention.

Outcome of the analysis of NIBC's portfolio shows that 79% of the portfolio should install a ballast water treatment system. 11% off the vessels should be sold, 1% should be scrapped and 9% of the vessels do not need to install a BWT system at all. The feasible strategy that postpones the investment of a BWT system with the smallest investment is followed. This can be realised either by planning the next special survey before the going into force date or by an early renewal of the IOPP certificate. In certain cases, the vessel will obtain the highest IRR when selling the vessel before the first dry-docking. This is the case when an up-tick in vessel value is expected, as the vessel value of today is assumed to be the initial investment.

When comparing the impact of the BWT system on the IRR, an exponential correlation between the age of the vessel and the impact can be found. The older the vessel, the higher the impact on IRR will be. This correlation is plotted and discussed for each of the five vessel types which are in NIBC's portfolio, namely: bulk carriers, product tankers, crude tankers, LPG carriers and container carriers. The average impact on IRR for each vessel type for NIBC's portfolio and the world fleet is shown respectively in figure 1 and 2. Figure 1 and 2 shows the range of impact on IRR for older and younger vessels, for both a high-price and low price ballast water treatment system.

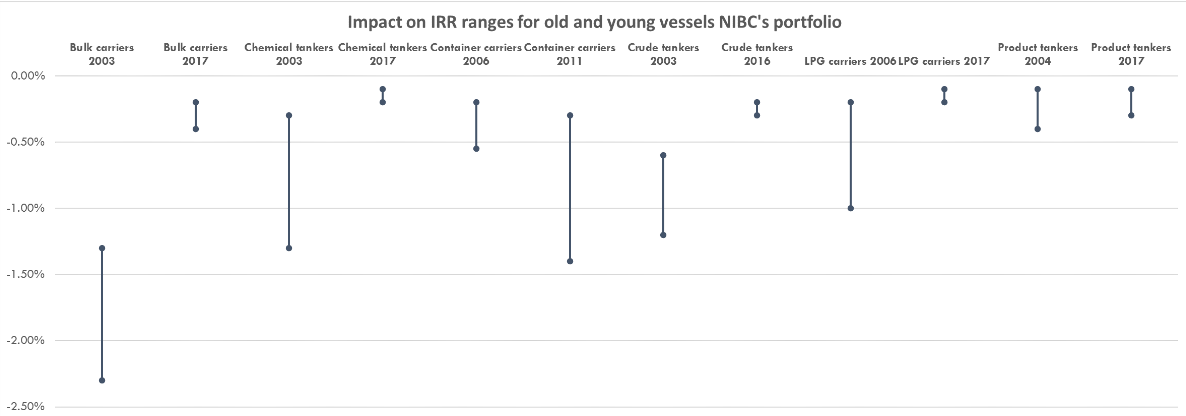


Figure 1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio.

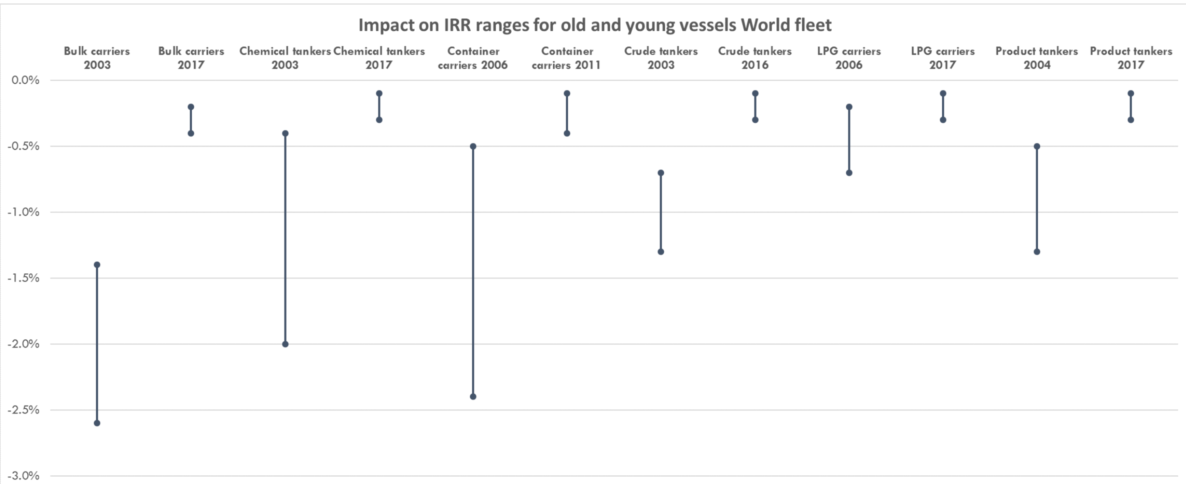


Figure 2: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet.

The largest impact is expected for bulk carriers. The main reason is a relatively low vessel value and a high ballast water pump capacity. This implies that the investment of a ballast water treatment system will have a large impact on the value of the vessel.

A database of the world fleet, with the same vessel types as in NIBC's portfolio, is created as a benchmark. The analysis based on the output of the tool of the almost 22,000 vessels shows that in general, NIBC's portfolio performs better compared to the world fleet. This is due to the fact that NIBC finances vessels within a certain risk profile.

The impact for NIBC

The impact of the total required investment for all vessels, within NIBC's portfolio, to comply with the BWM convention can be calculated. As not all ship owners will be able to make the investment for a BWT system, the bank may need to take action. Table 3 shows the total investment which is needed in the next five years. This investment represents between 2.3% and 5.2% of the value of the vessels as shown in table 3.

Total investment needed just for IOPP renewal	$ 26,000
Total investment needed for high-price BWT (including IOPP)	$ 315,000,000
Total investment needed for low-price BWT (including IOPP)	$ 126,000,000
Total vessel value	$ 4,930,000,000
Total impact low-price BWT as a percentage of the vessel value	2.6 %
Total impact high-price BWT as a percentage of the vessel value	6.4 %

Table 3: Total investment cost and impact on the entire NIBC portfolio

The installation of a BWT system can also impact the maximum loan amount that can be obtained because the cash flow models change with the new investment. The tool calculates the maximum loan to value for each vessel with a cash reserve of $ 500,000.- which is common in NIBC's financing structures. This implies that the cash flow of the vessel plus the additional $500,000.- cash reserve has to be sufficient to pay for the debt service of the loan. The maximum loan amount and the corresponding debt service that can be paid are calculated for loan amounts ranging from 10% to 100% in 10% increments. This is done for all vessels that require installation of a ballast water treatment system. The results show that container carriers and crude tankers are not impacted in the maximum loan to value by the BWT system. As expected, bulk carriers show the largest change in maximum loan to value of 7%, as this is in line with the large impact on the IRR. Chemical tankers, product tankers and LPG carriers all show around 1% to 2% impact on the maximum loan to value. This is in accordance with the findings for the impact on IRR which can be seen in figure 1.

Conclusions

From this research it can be concluded that there are many ways to comply with the ballast water management convention. From the 69 approved ballast water treatment systems the UV treatment, electrochlorination and inert gas systems are believed to be the most conventional in the coming years. Depending on the sailing profile of the vessel, a ship owner can make a decision on what ballast water treatment system fits best for its vessel. Different strategies can be applied to comply with the BWM convention which can be calculated with the use of the tool created for this research. The results show that almost all vessels will have to install a ballast water treatment system and that only 1% of NIBC's portfolio should be scrapped due to the investment of such a system. The average investment per vessel for NIBC's portfolio is between 2.6% and 6.4%.

Recent update on BWM implementation schedule

As from the 7th of July 2017, the MEPC approved draft amendments to the implementation of the BWM convention. Due to the flexibility of the tool a new run with this updated implementation schedule is executed. Due to this recent change this has not been incorporated in the entire report however a new run has been executed which is explained in chapter 12. The new implementation schedule postpones the installation date to the 8th of September 2019, for existing vessels but no IOPP renewal may be executed between 2017 and 2019. The findings of the change in implementation date can be found in additional chapter 12. The new average investment per vessel for NIBC's portfolio is between 2.4% and 6.1%.

Contents

Introduction

Ballast water, routinely taken on by ships for stability and structural integrity can contain thousands of microbes, algae and animals. When discharging this ballast water holding these organisms in a non-native ecosystem, new invasive aquatic species can be introduced. This could lead to devastating consequences for the local ecosystem. These so called aquatic "Invasive Alien Species (IAS)" proved to have a major impact on local ecosystems and even human health. By the end of 2016, hundreds of serious bio-invasions by AIS have been recorded around the world [**?**]. To prevent further disruption of different ecosystems all over the world, the Ballast Water Management Convention was adopted by the IMO in 2004.

This thesis investigates available possible solutions to comply with the BWM convention. The first step is to look into the convention and to see which parameters will influence the vessel-specific regulations. In depth research is done on the available technologies, the differences between them and the costs. This research shows what economic effect this will have on both ship owner and NIBC bank. The convention states that all vessels shall discharge ballast water through Ballast Water Management, according to the prescribed rules in the convention, after the first special survey as from the 8th of September 2017. The most evident solution is to install a ballast water treatment system. Multiple strategies can be followed to postpone the installation of the BWT system. The hypothesis is that in the case of vessels older than 15 years, the installation of a BWT system would be too expensive and that the vessels should be scrapped. By applying one of the strategies to postpone the installation, the vessel could still sail for a maximum of 5 years before it is scrapped. The goal of this research is to focus on the new IRR of the vessels after performing one of the strategies to comply with the regulation and show the impact of the BWM convention on the IRR. A tool is created in which the basic vessel parameters are the input and the ideal strategic solution is the output together with the new IRR. The tool is then used to analyse NIBC's portfolio. Finally the impact for ship owners and banks is evaluated. The NIBC bank can use this information to anticipate for potential problems with clients and to have a more in depth discussion with their clients on how to cope with the new regulations.

1
The ballast water management convention

Ballast water, routinely taken on by ships for stability and structural integrity can contain thousands of microbes, algae and animals. When discharging this ballast water holding these organisms in a non-native ecosystem, new invasive aquatic species can be introduced. This could lead to devastating consequences for the local ecosystem. These so called aquatic "Invasive Alien Species (IAS)" already proved to have a major impact on local ecosystems and even human health. Already hundreds of serious bio-invasions by AIS have been recorded around the world [**?**]. To prevent further disruption of different ecosystems all over the world, the Ballast Water Management Convention was adopted in 2004. This chapter will explain in more detail why the convention was adopted and what is stated in this convention.

1.1. The reasons behind the adaptation of the BWM convention

Merchant vessels all over the world make use of ballast water. As stability and structural integrity is designed for sailing with cargo, this ballast water is needed as additional weight for it to remain safe and effective while operating. When a vessel discharges its cargo, it will load ballast water. The vessel will bring the ballast water to the port of destination where it will load its cargo and discharge its ballast water. This ballast water may be contaminated with a variety of harmful substances, oil contaminants (in case of unsegregated tanks), non-native marine animals and plants. Besides that, the ballast water will also contain solid material that settles in the bottom of the ballast tanks as sediment. When species are transported to a non-native destination it can, under some circumstances, become established and in some cases dominant. These dominant non-native species are called aquatic invasive alien species (IAS). The introduction of these alien species could lead to devastating consequences for the local ecosystem.

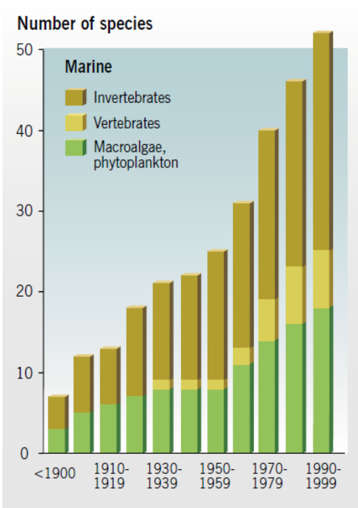


Figure 1.1: Number of alien species recorded in the marine environment [**?**].

As can be seen from figure 1.1, the accumulated number of recorded alien species in the Nordic/Baltic since 1900 demonstrates the continuing appearance of alien species. The Convention on Biological Diversity stated that the introduction of these immigrants due to ballast water exchange is one of the five main threats to the global bio-diversity. Change in bio-diversity can also have major economic impacts. In 1982 one of the worst bio-invasions took place in the Black Sea. When the comb jelly from North America was introduced, it took hold and grew in 6 years to an estimated 1 billion tonnes of species that was consuming vast quantities of fish eggs, larvae and zooplankton. By 1999, the annual losses caused by drops in commercial catches of marketable fish were estimated to be $ 500 million. The accidental introduction of another kind of comb jelly which is a predator of the previous one, resulted in a major decline and a substantial recovery of the ecosystem in the Black Sea . The introduction of the comb jelly is one of many cases where aquatic invasive alien

Articles	
Article 1	Definitions
Article 2	General Obligations
Article 3	Applications
Article 4	Control of the transfer of harmful aquatic organisms and pathogens through ships' ballast water and sediments
Article 5	Sediment reception facilities
Article 6	Scientific and technical research and monitoring
Article 7	Survey and certification
Article 8	Violations
Article 9	Inspection of ships
Article 10	Detection of violations and control of ships
Article 11	Notification of control actions
Article 12	Undue delay to ships
Article 13	Technical assistance, cooperation and regional cooperation
Article 14	Communication of information
Article 15	Dispute settlement
Article 16	Relationship to international law and other agreements
Article 17	Signature, Ratification, Acceptance, Approval and accession
Article 18	Entry into force
Article 19	Amendments
Article 20	Denunciation
Article 21	Depository
Article 22	Languages

Table 1.1: Overview of BWM convention articles. Source: 2004 IC for the control and management of ships ballast water and sediments

species had a major impact on both bio-diversity and the economy.

The growing global recognition of this problem lead to the convention on biological diversity (CBD) in 1992, which created a basis to protect biodiversity against invasive alien species. The international maritime organization IMO established a Ballast Water Working Group under the Marine Environment Protection Committee (MEPC) to actively search for solutions on the ballast water problem. MEPC developed an international legal instrument *"The International Convention for the Control and Management of Ships' Ballast Water and Sediments"* by consensus at a Diplomatic Conference at IMO Headquarters in London on the 13th of February 2004.

1.2. The international convention for the control and management of ships' ballast water and sediment

The MEPC developed an international legal instrument in the form of the international convention for the control and management of ships' ballast water and sediments. The convention desires to *"continue the development of safer and more effective Ballast Water Management options that will result in continued prevention, minimization and ultimate elimination of the transfer of Harmful Aquatic Organisms and Pathogens"* (IMO, 2004). Next to the IMO BWM convention, other national concerns came up. The most drastic and influential regulations and guidelines concerning the introduction and spread of alien species came from the United States Coast Guard (USCG). These regulations became effective on the 21th of June 2012.

On the 8th of September 2016 Finland signed the BWM convention, at that moment 30 states representing the required 35% of the world merchant shipping tonnage ratified the convention. The convention stipulated that it would go into force 12 months after this ratification, meaning September 8th 2017. The BWM convention consists of 22 Articles and an Annex with Section A through E containing multiple regulations. MEPC published a list of 14 guidelines for uniform implementation of this BWM convention. In Table 1, 2 and 3 an overview of these articles, annex and guidelines is given.

Section A	General provisions
Regulation A-1	Definitions
Regulation A-2	General Applicability
Regulation A-3	Exceptions
Regulation A-4	Exemptions
Regulation A-5	Equivalent compliance
Section B	**Management and control requirements for ships**
Regulation B-1	Ballast water management plan
Regulation B-2	Ballast water record book
Regulation B-3	Ballast water management for ships
Regulation B-4	Ballast water exchange
Regulation B-5	Sediment management for ships
Regulation B-6	Duties of officers and crew
Section C	**Special requirements in certain areas**
Regulation C-1	Additional measures
Regulation C-2	Warnings concerning ballast water uptake in certain areas and related flag state measures
Regulation C-3	Communication of information
Section D	**Standards for ballast water management**
Regulation D-1	Ballast water exchange standard
Regulation D-2	Ballast water performance standard
Regulation D-3	Approval requirements for ballast water management systems
Regulation D-4	Prototype ballast water treatment technologies
Regulation D-5	Review of standards by the organization
Section E	**Survey and certification requirements for ballast water management**
Regulation E-1	Surveys
Regulation E-2	Issuance of endorsement of a certificate
Regulation E-3	Issuance or endorsement of a certificate by another party
Regulation E-4	Form of the certificate
Regulation E-5	Duration and validity of the certificate

Table 1.2: Overview of BWM convention Sections [**?**]

Guidelines	
G1	Guidelines for sediment reception facilities
G2	Guidelines for ballast water sampling
G3	Guidelines for ballast water management equivalent compliance
G4	Guidelines for ballast water management and development of ballast water management plans
G5	Guidelines for ballast water reception facilities
G6	Guidelines for ballast water exchange
G7	Guidelines for risk assessment under regulation A-4 of the BWM convention
G8	Guidelines for approval of ballast water management systems
G9	Procedure for approval of ballast water management systems that make use of active substances
G10	Guidelines for approval and oversight of prototype ballast water treatment technology programs
G11	Guidelines for ballast water exchange design and construction standards
G12	2012 Guidelines on design and construction to facilitate sediment control on ships
G13	Guidelines for additional measures regarding ballast water management including emergency situations
G14	Guidelines on designation of areas for ballast water exchange

Table 1.3: Overview of BWM convention guidelines [**?**].

1.2.1. Regulation A – General provisions

The BWM convention states that for all flag flying vessels, except where expressly provided otherwise, the discharge of ballast water shall only be conducted through ballast water management in accordance with its annex. Exceptions are made in case of emergency like preventing damage to the ship and/or its equipment or saving life at sea. Exemptions can be made to vessels that only sail between specified ports or locations and no mixture of ballast water has taken place. Pleasure crafts solely used for recreation, competition or search and rescue that have less than 50 LOA and with a maximum ballast water capacity of 8m3 will be determined by the flag state according to the MEPC (IMO) guidelines.

1.2.2. Regulation B – Management and control requirements for ships

Every vessel shall have a vessel-specific ballast water management plan, which is approved by the classification bureau according to the guidelines written by the MEPC (IMO). The written ballast water management plan includes a detailed description of the procedures and coordination of the involved discharge to sea with the authorities of the state in which such discharge will take place. It also describes the removal and disposal of sediments from spaces designated to carry ballast water.

Next to this management plan, every vessel shall have a ballast water record book, or electronic record system, on board. This record book has to contain a very detailed movement log for the ship's ballast water with at least the information specified in Appendix II of the BWM convention. The record book has to be kept readily available for inspection including a historical record of two years, whereafter the company will keep the record for a minimum of three more years. Regulation B-3 of the convention stipulates an implementation plan for three ranges of construction dates and three ranges of ballast water capacity. As the implementation plan was only constructed until 2016, all vessels will have to comply with the standard described in regulation D-2 when the regulations go into force. Vessels that discharge ballast water to a specially designed reception facility that follows the guidelines developed by the MEPC (IMO) do not have to comply with the D-2 regulation.

1.2.3. Regulation C – Special requirements in certain areas

Additional measures to regulation B to further prevent transfer of harmful aquatic organisms through ballast water may be taken by individual parties.

Each party shall report all requirements and procedures relating to ballast water management, including its laws, regulations, and guidelines for the implementation of the BWM convention to the IMO. Secondly it shall consult with adjacent or other states that may be affected by such additional measures. A party introducing additional measures shall endeavour to provide all appropriate services in order to ease the ship's burden.

Known harmful conditions of water in certain areas which are likely to influence the uptake or discharge of ballast water shall be notified by the party of that specific area. Water that is known to contain outbreaks, infestations, populations of harmful aquatic organisms and pathogens or where tidal flushing is poor will be considered. All shall be notified to mariners under a party's jurisdiction, the IMO and any potentially affected coastal states [**?**]. The IMO shall then, through all appropriate means, make the information available.

1.2.4. Regulation D – Standards for ballast water management

Regulation D of the convention is about all standards of the ballast water management in respect to the management itself, the approval of certain systems, etcetera. Regulation D-1 is about the ballast water exchange standard which was created to slowly stipulate the implementation of the final D-2 regulation. As mentioned before, these dates of implementation have expired, so all vessels have to meet the D-2 regulation standards.

The D-2 regulation states: *"Ships conducting Ballast Water Management in accordance with this regulation shall discharge less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension and less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations described in paragraph 2."* [**?**].

Microbes, as a human health standard, shall include:

- Toxicogenic Vibrio cholerae (O1 and O139) with less than 1 colony forming unit (cfu) per 100 millilitres or less than 1 cfu per 1 gram (wet weight) zooplankton samples.
- Escherichia coli less than 250 cfu per 100 millilitres.
- Intestinal Enterococci less than 100 cfu per 100 millilitres.

Next to the requirements of regulation D-2, all ballast water management systems must be approved by the flag state, taking the guidelines developed by MEPC (IMO) into account. Ballast water management systems that make use of active substances or preparations shall follow the IMO G9 guidelines. The used ballast water management systems should at all times be safe in terms of the ship, its equipment and the crew. A vessel can, prior to the date that the D-2 regulation becomes effective, participate in a program approved by the IMO to test and evaluate promising ballast water treatment technologies. This testing may only be executed by the minimum number of ships necessary to effectively test the technologies. For such ships the standard in the D-2 regulation will cease to apply for five years from the date the ship would otherwise be required to comply with these standards. Throughout the testing and evaluation period, the ballast water treatment systems shall be operated consistently and as designed.

Regulation D-5 states that at least three years prior to the going into force of regulation D-2, the MEPC shall undertake a review. This review about appropriate technologies has to take into account: safety relating the ship and crew, the environmental acceptability so that the technology is not causing more environmental impact than it solves, practicability so that the technology is compatible with the ship design and operation, the cost effectiveness and lastly the biological effectiveness in terms of removing harmful aquatic organisms and pathogens in ballast water.

1.2.5. Regulation E – Survey and certification requirements for ballast water management

All vessels of 400 GT and above to which the convention applies, excluding floating platforms, FSUs and FPSOs, shall be subject to a number of surveys specified in regulation E-1 of the convention. These surveys will be listed and explained briefly below.

1. Initial survey before ship is put into service or before the certificate required under E-2 or E-3 is issued for the first time. The survey shall verify if the requirements by regulation B-1 and anything associated, comply with all the convention requirements.

2. A renewal survey with an interval specified by a state's government, but not exceeding five years. Some exceptions are made and will be discussed later. The survey will again verify whether the requirements by regulation B-1 and anything associated, comply with all the convention requirements.

3. An intermediate survey within three months before or after the second or third anniversary date during one of the annual surveys specified in the 4th survey. The intermediate surveys shall ensure that the equipment, systems and process of ballast water management fully comply with the requirements and are in working order.

4. An annual survey within three months before or after the anniversary date is given, including a general inspection of the structure, equipment, systems and processes associated with the required ballast water management plan. All this, to ensure they all have been maintained in accordance with the regulation.

5. An additional general or partial survey, according to the circumstances, is required after a ship has made changes, replacement or significant repair of the structure, equipment, systems and anything associated with the ballast water management. This survey is executed to ensure that the ship still complies with the requirements of the convention.

All flag states shall establish appropriate measures for ships that do not comply with these surveys in order to ensure that the provisions are complied with. The surveys mentioned above shall be carried out by officers of the flag-flying state or special assigned surveyors from the state. These special assigned surveyors and their specific responsibilities and conditions of the authority shall be notified to the IMO. When during a survey it is determined that the ship does not comply with the requirements from the convention, immediate corrective action has to be taken to bring the ship back into compliance. The surveyor shall then make sure that the ballast water management certificate is not issued or is withdrawn, as appropriate. If the ship is in the port of another party, the appropriate authorities of the port state shall be notified immediately so that actions can be taken. Whenever an accident occurs to a ship causing significant damages to the integrity of the ballast water management system, the issuing party shall be informed and immediate action will be taken. The party will investigate whether a new complete survey is necessary. When the ship is in another port, it will report to the appropriate authorities.

After a successful completion of a survey conducted according to the regulations mentioned above, a ballast water management certificate is issued. A certificate issued by one party shall always have the same validity as other parties. The flag state will always have full responsibility for the given certificate within their flag state. The certificate shall be drawn up in the official party's issuing language. If this language is neither English, French nor Spanish, the text shall include a translation into one of these languages.

1.3. Ballast water management implementation

Since the 2004 BWM convention, the industry is aware of the fact that new technologies were needed to comply with this convention. The going into force of the convention will affect all merchant vessels that carry ballast water. This implies a large growing market coming up. A recent calculation estimated a turnover of around $50-74 billion for purchasing and installing all the ballast water treatment systems [**?**]. As all vessels have to comply with the new regulation, manufacturing ballast water management systems can be a lucrative business. When in 2008 the IMO adopted the G8 guidelines *"Guidelines for approval of ballast water management systems"* manufacturers of ballast water treatment systems started to come up. Now that the going into-force date, the 8th of September 2017, is known, ship owners and financiers are investigating the different possible solutions for their vessels. A list of D-2 basic and final approved ballast water management systems is published by the IMO. Taking this list together with the list of approved systems by different administrations makes a total of 31 approved systems. As the MEPC announced another change in G8 guidelines in the MEPC 70th session, manufacturers, ship owners and financiers are confused. During the MEPC 70th sessions, Liberia, India and the international chamber of Shipping (ICS) suggested to postpone the going into force for another two years to give manufacturers and ship owners time to comply with the new G8 guidelines. A decision on this request will be made during the 71st session which is planned in May 2017. Manufacturers who have been waiting for almost 12 years for the convention to become mandatory and sold a little number of systems, state that they cannot wait for another two years. All these uncertainties make it difficult for ship owners and manufacturers to make decisions on how to act.

2

Ballast water and treatment methods

This chapter will explain the need for ballast water aboard a vessel in more detail. Besides the location of these ballast water tanks, the pump capacity is an important characteristic for choosing a ballast water treatment system. The different ballast water treatment methods will be discussed in the last section.

2.1. The use of ballast water

Merchant vessels make use of ballast water to maintain stability and structural integrity while sailing. Next to stability, ballast water can trim the vessel so that the propeller is fully submerged in ballast condition. The type, size and number of ballast tanks are related to the size and type of the vessel. While older vessels occasionally make use of cargo holds or other non-segregated tanks, most of today's vessels make use of segregated ballast water tanks. These tanks are located depending on the vessels type. The design, location and volume of ballast tanks are mainly established by the required draft, trim, hull loading limitations, the required vertical centre of gravity, acceleration and slamming reduction. There are three main configurations for ballast tanks, each with a different application.

The ballast tanks of most bulk carriers are placed in the double bottom (DBT double bottom tanks) and underneath the main deck on port- and starboard side (TST topside tanks or upper wing tanks). Tankers, container vessels and some of the newest bulk carriers carry their ballast water in double bottom tanks (DBT) and in tanks along the port- and starboard side of the vessel (ST side tanks or WT wing tanks). Ro-Ro and General cargo vessels generally have double bottom tanks (DBT) to keep the centre of gravity low. Also tanks located in the bow and stern (FPT forepeak tank and APT aft peak tank) are used to add ballast and to trim the vessel so that the propeller is fully submerged. Figure 2.1 shows a schematic overview of the different segregated ballast water tanks.

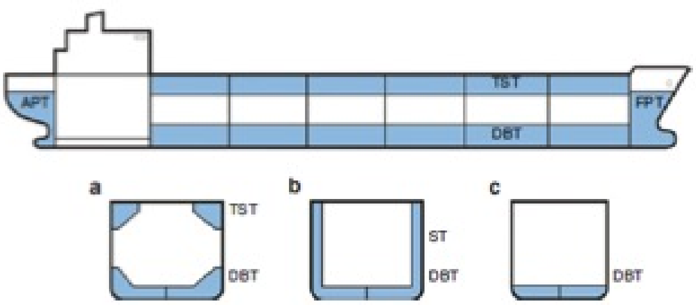


Figure 2.1: Ballast tanks on: (a) most bulk carriers, (b) tankers, container vessels, and some newest bulk carriers, and (c) Ro-Ro and general cargo vessels. (APT aft peak tank, DBT double bottom tanks, FPT forepeak tank, ST side tanks, TST topside tanks or upper wing tanks) [**?**]

To know the vessel's seaworthiness, it is important to know the exact amount of ballast water in each tank. In the past this measurement was done by sounding tables which were inserted in sounding pipes to calculate the exact amount of ballast inside. Modern ships are usually equipped with digital measurement systems but are obliged to have sounding pipes for redundancy in case of a system breakdown.

2.1.1. Ballast water capacity

The ballast capacity of a vessel is the total volume of all the ballast tanks. The size of the tanks is related to the cargo capacity of the vessel. In general it can be said that the more cargo the vessel is able to carry, the more ballast water is needed when sailing empty. As the ballast tank capacity is related to the cargo weight, the amount of ballast water related to the DWT of a vessel differs per vessel type. An NIBC's portfolio database of 291 vessels has been created to confirm these findings. Data from significant ships [**?**], [**?**], [**?**] is additionally used to have a more complete overview. The database is divided into six main vessel-types: Container carrier, Bulk carriers, Gas (LPG) carriers, Chemical tankers, Product tankers and Crude tankers. These types are chosen because they load, discharge and sail under approximately the same ballast conditions. These vessel-types will be discussed throughout the research because they cover almost the entire NIBC's portfolio. The database provides an estimate of the required ballast water capacity per vessel-type. These estimations can be found in table 2.1.

vessel-type	**Ballast water capacity percentage of DWT**
Container carriers	31%
Bulk carriers	34%
Gas carriers	57%
Chemical tankers	41%
Product tankers	42%
Crude tankers	30%

Table 2.1: Ballast water capacity percentage of DWT per vessel-type. Source: Ballast water capacity per vessel-type. (Appendix A)

2.1.2. Ballast water pump capacity

The ballast water pump capacity is the total pump capacity which can be used to load or discharge the ballast tanks. These ballast tanks are loaded with the vessel's surrounding water. The ballast water pipelines linked with a ballast pump, connect the vessels sea-chest(s) and strainer(s) with the ballast tanks. Larger vessels usually carry two separate ballast water pumps for redundancy while smaller vessels may use the service pumps, which are normally used for bilge water and fire-fighting, as a ballast water pump. The insights on the placement of ballast water tanks and the importance of weight distribution and pump capacity will give a better understanding of the differences and important factors when looking at various ballast water treatment systems.

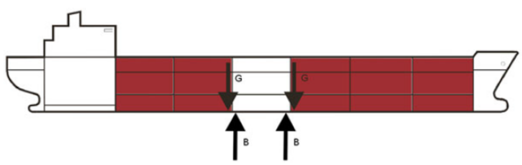


Figure 2.2: Arrows indicating where in this case shear forces act. Two coincidentally tank sections, one being fully ballasted bearing more gravity (G) than the empty tank section, where the buoyancy (B) effect is stronger.

The capacity of the ballast water pumps is related to the cargo operation. The higher the loading capacity of the cargo, the higher the ballast water pump capacity has to be. The cargo loading capacity is dependent on the capacity of the terminal. The different terminals vary in loading rates but require the ship owner to have sufficient ballast pump capacity to make sure that the terminal operation is not slowed down. This comes down to having approximately the same ballast pump capacity as the loading rates of the terminals.

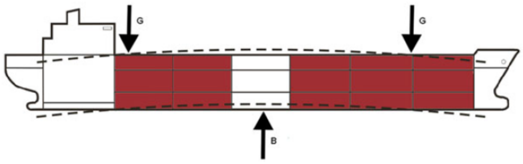


Figure 2.3: Arrows indicating the bending forces with increased buoyancy (B) at the midship and increased gravity (G) in for and aft part, causing longitudinal deflection of the vessel hull, so called hogging.

Another reason to have the same cargo operation speed and ballast water pump capacity is to keep the vessels structural integrity. Because loading or discharging cargo has a large impact on the weight distribution in the vessel, it is important to equalize this by loading or discharging ballast water.

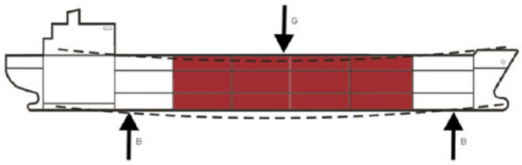


Figure 2.4: Arrows indicating bending forces with increased buoyancy (B) in the for and aft part and increased gravity (G) in midship part, causing longitudinal deflection of the vessel hull, so called saggin.g

Incorrect weight distribution can cause critical shear stress and bending moments as shown in Figure 2.2, 2.3 and 2.4.

2.1.3. Ballast pump capacity estimation

Most of the ballast water treatment systems that will be discussed in this report work with an in-line method. This implies that the treatment system is placed in-line with the ballast water piping of the vessel. For treatment systems that work with an in-line method, the most important design parameter is the ballast water pump capacity. As this parameter is not publicly disclosed in most cases[**?**], a calculation is needed to estimate the ballast water pump capacity. This can then be used to analyse the world-fleet and the NIBC's portfolio. Data is gathered to find a relation between the DWT of a specific vessel-type and the ballast water pump capacity. A database with the NIBC's portfolio is created to have a detailed overview of the fleet [**?**].
As the ballast pump capacity is dependent on the terminal operation capacity, it is also dependent on the type of cargo it carries. The ballast tanks are usually filled 100% so that no free surface effects occur. This would imply that the ballast water discharge time of a full tank is equal to the loading time of the terminal. The ballast water discharge time of each vessel-type is calculated by dividing the total ballast water capacity with the ballast water pump capacity. This is done for the 108 vessels from the database, which were provided with both ballast capacity and ballast pump capacity. Comparing the discharging time of ballast water with the loading time of the cargo gives a confirmation of the one-on-one correlation [**?**].

$$Ballast \quad discharge \quad time \quad (h) \quad = \frac{Ballast \quad water \quad capacity \quad m^3}{Ballast \quad water \quad pump \quad capacity \quad \frac{m^3}{h}} \tag{2.1}$$

These loading times are plotted compared to the DWT of the vessels, this is shown in figure 2.5. It can be seen that the average loading time is approximately between 10 and 20 hours. These loading times are verified by the different terminals and ship owners as plausible. As too little data could be found on gas carriers, an average of 12 hours is considered for these vessel types because this is considered the average loading time of a LPG gas carrier [?] [?] [?] [?] [?] [?] [?].

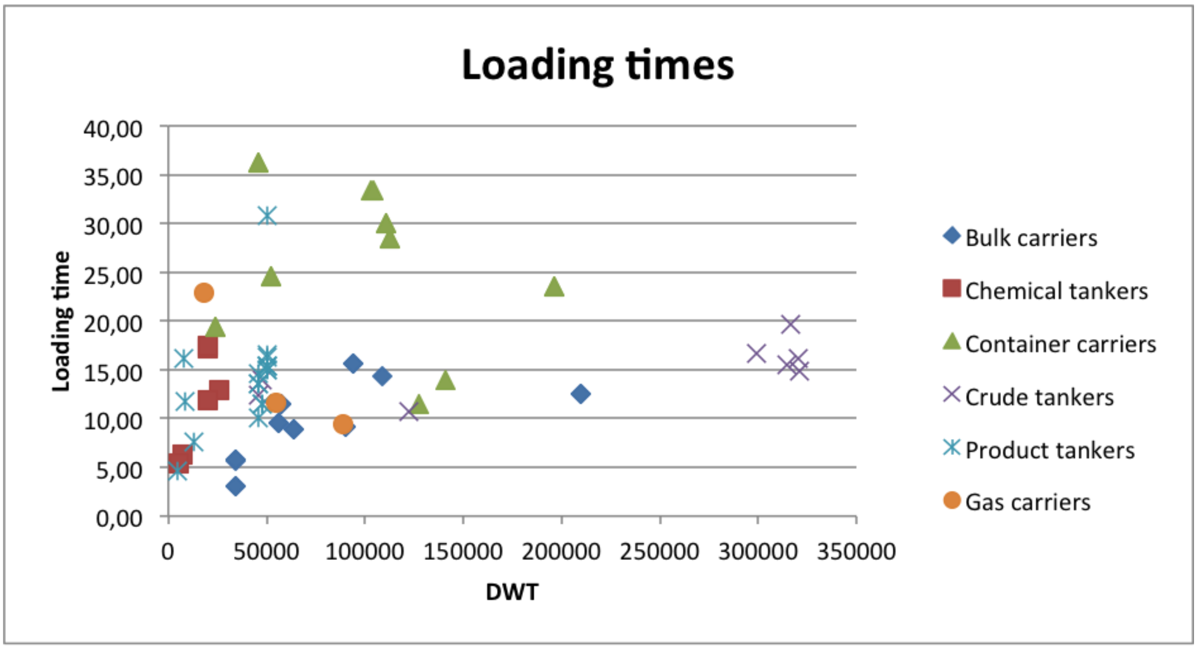


Figure 2.5: Loading time of different vessel-types [?] [?] [?] [?].

Figure 2.5 shows that with container carriers there is little correlation between the DWT and the loading times. Ballasting for container vessels is separate kind of operation compared to the rest of the vessel-types because of two main reasons.

1. Container carriers use ballast water in loaded conditions to lower the center of gravity

2. Loading rates are low

Container carriers carry lots of containers which are stacked. To prevent the center of gravity of rising too high, ballast water is used in these loaded conditions. Loading rates of containers are lower compared to the loading rates of for instance bulk carriers. Loading rates of 16,000 tonnes per hour are not uncommon for bulk carriers [?]. The biggest container terminal in Rotterdam ECT can load up to 150 moves per hour, with an average of 13 tonnes per TEU and a 1.6 relation between twenty and forty foot containers, it comes down to 3,120 tonnes per hour [?]. With these much lower loading rates, the ballast water pump capacity is not dependent on the loading rates in most cases. Nevertheless a clearer correlation between the DWT and the ballast pump capacity can be found for the container carriers.

Considering that the loading time is equal to the ballast water discharge time, the ballast pump capacities can be calculated. When taking both the correlation between DWT/Loading time and DWT/Ballast capacity, the ballast water pump capacity can be calculated for the six vessel-types solely based on vessel-type and DWT. This means that there is a correlation between DWT, the vessel-type and the ballast pump capacity just as could be found for container carriers.

The 110 vessels from the database that were provided with both DWT and ballast pump capacity were used to find the correlation per vessel-type. For all vessel-types, except for the gas carriers, a linear correlation could be found. These figures with the empirical correlation per vessel-type can be found in appendix A. The correlations can be found in table 2.2. For gas carriers a 12 hour de-ballasting profile is considered as mentioned before.

vessel-type	Correlation
Crude tankers	0.0150X+1276.10
Container carriers	0.0124X+167.90
Bulk carriers	0.0223X+974.29
Chemical tankers	0.0094X+369.21
Product tankers	0.0282X+136.17

Table 2.2: Correlation between DWT and ballast pump capacity per vessel-type. Where X is the DWT of the vessel.

This calculation is done for both the NIBC's database of 291 vessels and the world fleet according to Clarksons [?]. This shows the demand for ballast water treatment systems in relation to the size. Figures 2.6 and 2.7 show the calculated ballast water pump capacities for the NIBC's - and the world fleet respectively.

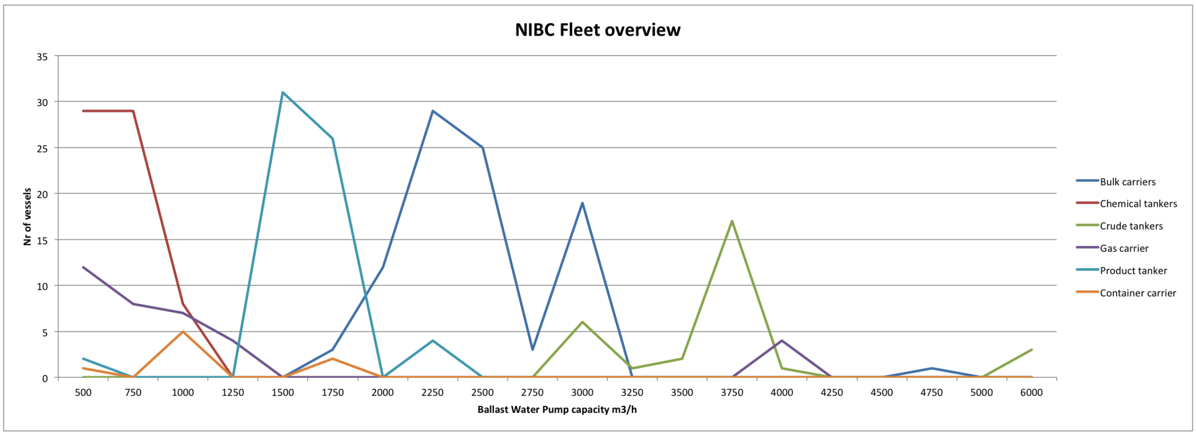


Figure 2.6: NIBC's fleet overview of ballast pump capacities [?] [?] [?] [?].

By comparing these two graphs it can seen in which segment NIBC's is operating compared to the world fleet according to ballast water pump capacity. This gives a sense on where the competition of NIBC's clients are operating and creates a possibility to see whether clients have an advantage or disadvantage compared to the world fleet. For the NIBC's fleet three peaks of capacities can be found. Small chemical tankers with capacities around 750 m3/h cover one of the three peaks. This same peak is found in the world fleet, meaning that the demand will be high for this capacity group. The other two peaks of product tankers with capacities around 1,500 m3/h, and bulk carriers with capacities around 2,500 m3/h can also be found in the world fleet analysis. In this case, the world fleet shows relatively little presence for these capacity ranges. This suggests more competitiveness in the chemical tanker range, compared to the range of bulk carriers and product tankers. Lastly a small peak can be found for bulk carriers, crude tankers and gas carriers with capacities of around 3500 m3/h. This is a capacity which can barely be found in the world fleet analysis.

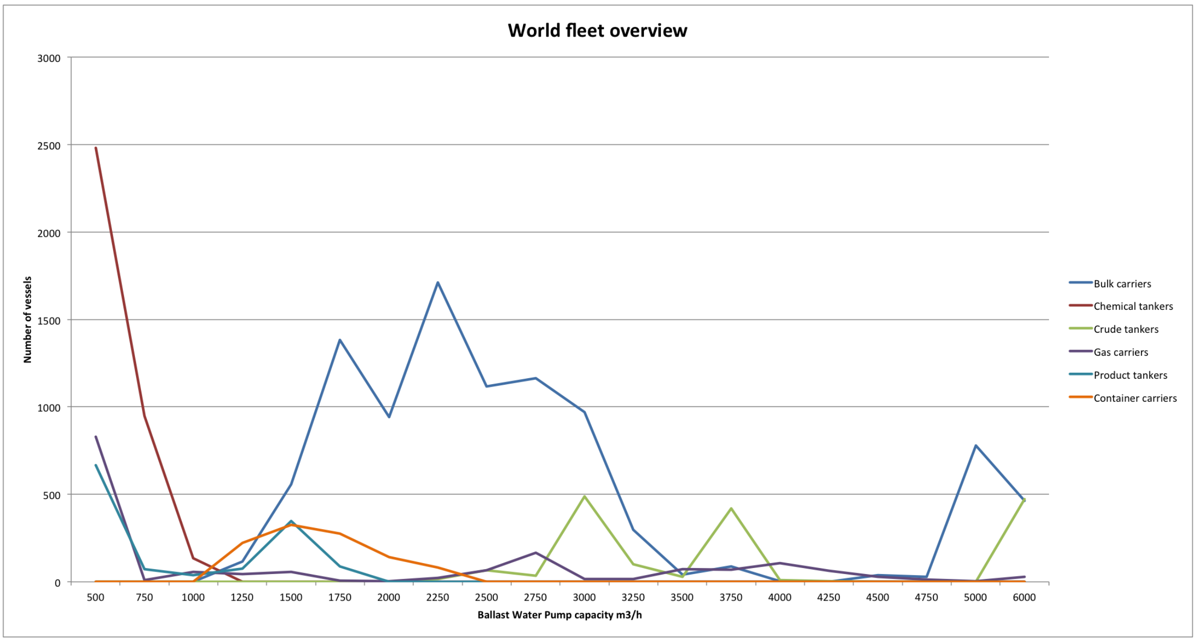


Figure 2.7: World fleet overview of ballast pump capacities [?] [?] [?] [?].

2.2. Ballast water treatment methods

In the following sections, the types of ballast water treatment methods will be discussed. Multiple water treatment technologies are used and applied in different stages of the ballasting process. The treatment process can be split up in three main stages:

1. Pre-Treatment
2. Treatment
3. Neutralization

The first stage is the pre-treatment that takes place at the intake of the ballast water. In this stage, large solid particles and species are captured to ease the actual treatment which follows. The second stage is used to affect and/or remove all organisms left. The third stage makes sure that the active used substances are neutralised and no harmful toxic residual is discharged with the treated ballast water. Figure 2.8 shows these three stages with the main treatment methods.
The different treatment technologies will be discussed in the following sections. The different treatment technologies are split up in three technology types: mechanical, chemical and physical treatment. The different types of technologies are indicated with the three symbols shown in the legend of figure 2.8.

2.2.1. Pre-treatment technologies

The so called pre-treatment of the ballast water is mainly done by filtration, a hydrocyclone, coagulation, flocculation or a combination of the forgoing processes. The goal of pre-treatment of the ballast water is to make sure that large particles and organisms are removed to increase the efficiency of the actual treatment in the second stage.

Filtration 

Filtration of ballast water as a pre-treatment method can be executed by disk filters, mesh and wedge-wire filters. Ultra-filtration, a filtration method to remove much smaller particles, has not been proven yet. The volumes of the ballast water are too large to perform this kind of filtration. A filtration system can be built up out of single or multiple filters. The advantage of the use of multiple filters is the filtration in multiple stages. The first stage will filter out the largest particles, wereafter smaller particles can be filtered out without compromising on efficiency. These filters are usually automatically rinsed by the use of backwash. Backwash

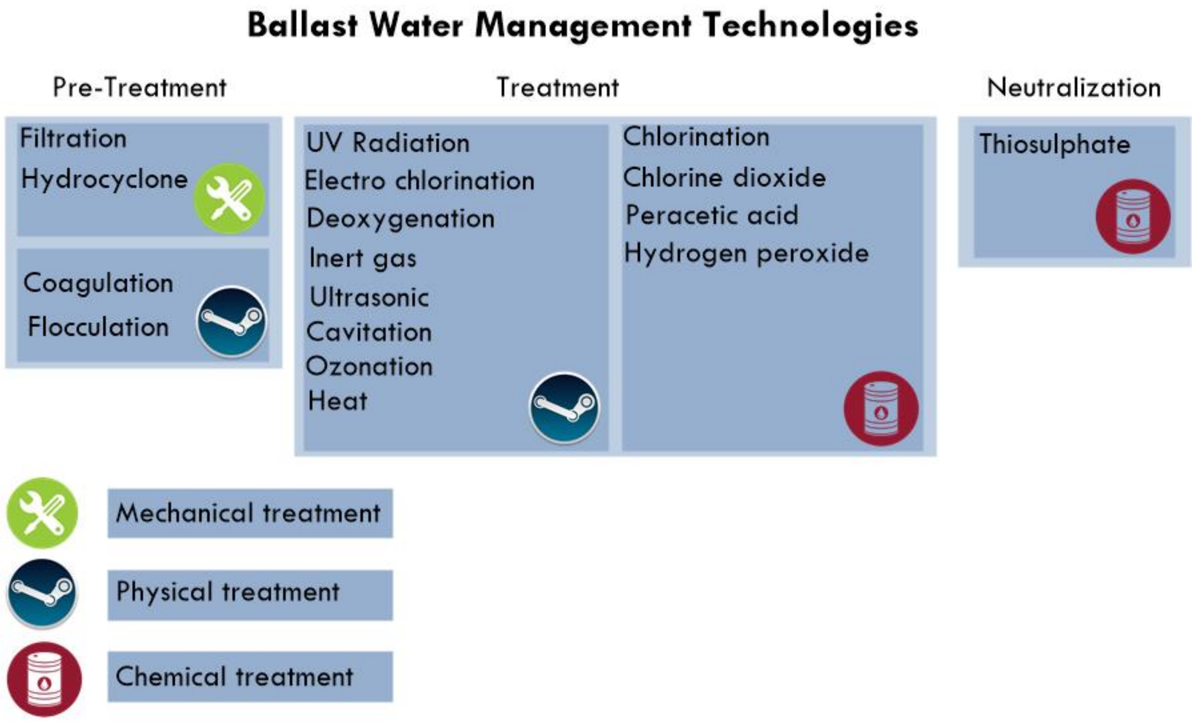


Figure 2.8: Ballast water treatment methods and types

is the concept were freshwater flows backwards through the filters to clean and dispose the filtered particles in their natural environment. These filter systems are relatively easy to manufacture which makes it a cost-efficient method. Unfortunately these filtration methods have not yet shown to have enough capacity to use as a stand-alone ballast water management system [**?**].

Hydrocyclone 

A hydrocyclone is a piece of equipment mainly used in mining to handle large volumes of slurry and to separate bigger particles. The principle of separating particles of different sizes and density can be used as a pre-treatment method to take out the larger particles in ballast water. The water is injected under pressure into the inlet feed. Due to the pressurised water inlet in the Feed, the water starts to cyclone inside the hydrocyclone. The spinning effect forces larger and more dense particles to the outside of the cone to primary vortex were they eventually disappear through the underflow at the bottom of the hydrocyclone. The water with the lighter particles will enter the secondary vortex and leave the hydrocyclone through the overflow on top of the equipment. This is a relative inexpensive way of separation. As the particles with the same density as water will slip through, this system is primarily used for pre-filtration. This can help the ballast water treatment system to work more efficient [**?**].

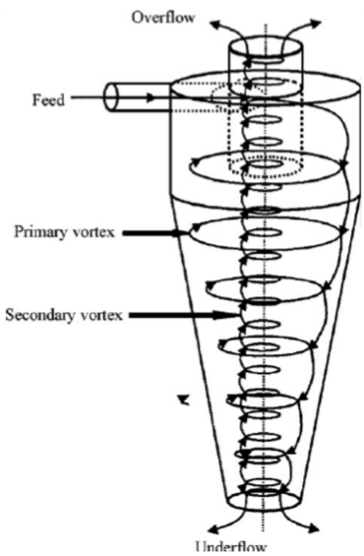


Figure 2.9: Basic technical drawing of a hydrocyclone [**?**]

Coagulation 

The term coagulation in water treatment means adding a coagulant to the water to destabilize colloidal suspension. Colloidal suspension is a substance that has solid particles permanently suspended in a liquid. This colloidal suspension is kept by the electrical charges of these solid particles with the same charge [**?**]. Coagulation uses a coagulant with the opposite charge to destabilize the suspension and cling together to form micro floc. As this micro floc is still not visible with the naked eye, flocculation is mainly used to create bigger particles that can then be treated by flocculation.

Flocculation

The flocculation process is used to increase the size of the micro floc created by coagulation to visible suspended particles. This is done by gentle mixing of the liquid causing the micro flocs to collide and cling together into bigger particles. The relatively time consuming procedure continues until the ideal size and weight of the particles has been reached. These particles can then be removed by the use of filtration [**?**].

2.2.2. Treatment technologies

The treatment stage is where the actual ballast water treatment takes place. The different methods are divided in two treatment types: physical and chemical. All treatment technology methods will be explained and analysed briefly in this chapter.

2.2.3. Physical treatment technologies

Physical treatment technologies are technologies that do not make use of active substances. Instead it uses physical aspects to filter out, disarm or kill harmful microorganisms. Some physical treatment technologies may produce chemical products like chlorine.

UV radiation

The ultraviolet energy is an invisible radiation which is found in the electromagnetic spectrum between the visible light and x-rays. The UV rays have to penetrate the cell and disorder the cell's DNA to ensure sterilization of the organism. The sterilised organisms are then discharged with the ballast water without the possibility of reproducing itself [**?**]. The disadvantage is the fact that the costly UV lamps have to be replaced once a while [**?**].

Electro chlorination

Electro chlorination is the process where hypochlorite is produced by the salty water in combination with an electric current which triggers the electrolysis. The electrolysis turns water and salt into sodium hypochlorite and hydrogen gas as shown in equation 2.2.

$$NaCl + H2O + Energy \rightarrow NaOCl + H2 \tag{2.2}$$

This method is widely used in drinking water treatment plants and to disinfect swimming pools. The big advantage is that no chemicals have to be carried by the vessel. The disadvantage of this process is that next to chlorine, hydrogen gas is produced. This hazardous gas has to be controlled. The produced chlorine will also cause a more rapid corrosion process inside the piping and tanks [**?**]. In most cases a neutralizing substance needs to be added to the water before discharge.

Deoxygenation by nitrogen

Deoxygenation of water is the process where oxygen is distracted from the water. The deoxygenation of seawater by the use of nitrogen is proved to be an effective treatment against most organisms found in ballast tanks. Another positive aspect is that the deoxygenation will minimize the corrosion inside the ballast tanks. Deoxygenation by nitrogen is an expensive method although the anticorrosion benefit of this technique is an economic incentive [**?**]. However, fact is that some anaerobic species and organisms with cyst stages could survive a transoceanic journey in a nitrogen treated tank makes it a less likely method for treating ballast water with the strict IMO and USCG regulations.

Inert gas

This is a method where inert gas is infused in the filled ballast tanks. This will start a de-aeration process in the water, diluting the O_2 concentration to such level where most organisms cannot survive [**?**]. The elevated level of CO_2 in the inert gas temporarily reduces the pH level of the water. This also causes hypoxia and a condition known as hypercapnia. These water conditions are fatal for both aerobic and anaerobic species. Next to that, the low *02* concentration in the tanks will slow down the corrosion process. To meet the IMO standards the deoxygenation process will take more time than other treatment solutions, which makes this method more suitable for long range vessels. The fact that ballast water is not treated at the intake makes this treatment method independent on the pump capacity of the ballast tanks which is a big advantage especially for large vessels with high capacities.

Ultrasonic and cavitation treatment

Ultrasonic treatment uses ultrasonic pulses with a specific frequency to affect the structural integrity of the organisms at cell level. Some frequencies of the ultrasonic treatment can induce acoustic cavitation. Cavitation is caused by the rapid change of pressure in a running fluid. Vapour of the fluid implodes causing a shock wave. Cavitation is generally considered an unwanted incident, as the implosions cause serious damage to for instance propellers, pumps and piping. Where acoustic cavitation is induced by ultrasonic waves through a medium like water, hydrodynamic cavitation is caused by velocity variation in the flow. Energy consumption for inducing acoustic cavitation varies between 3 and 43% while hydrodynamic cavitation varies between 54 and 60% [**?**]. The destruction of marine species by acoustic cavitation is a method used for over 80 years and proved to be very effective on zooplankton larger than 100 μm but remains to insufficient for smaller species [**?**].

Ozonation

With the ozonation method an unstable ozone gas is inserted in the ballast water. As it reacts with the water, it decomposes and causes a chemical reaction which kills micro-organisms. Environmental awareness on the use of chlorine resulted in the use of ozone as a biocide. The ozone gas is generated by atmospheric oxygen which flows through a high voltage discharge gap from the ozone cells. Ozonation has been proved to be a good solution in industrial applications. As the industrial generators are bulky and complex, large capacity ozone generators are not currently used for marine purposes. The injection of ozone causes the same residual as with chlorine injection [**?**].

Heat treatment

By heating up the ballast water micro-organisms cannot longer survive. The advantage is that the ballast water can be used to cool the engine and at the same time disinfect the ballast water [**?**]. The basic principle is explained in figure 2.10.
This method heats up the ballast water up to 45ºC for a long period of time, which kills large species such as fish. For micro-organisms, this method is not as effective enough[**?**]. Also the installation of such a system, which requires a lot of piping, would be a difficult task when considering a retrofit.

2.2.4. Chemical treatment technologies

The use of chemicals to treat water is commonly used in land based operations. The biggest difference with sea based operations is the need for chemical storage. Next to that, the availability in ports of these chemicals is crucial considering additional regulations and restrictions when a vessel carries chemicals. The chemicals mainly used in the IMO approved ballast water treatment systems will be discussed briefly.

Chlorine chemical injection

Chlorine is one of the best known disinfectants to treat water. It is mainly used to disinfect drinking water. Adding chlorine to water destroys the cell walls of harmful micro-organisms and is one of the approved technologies by the IMO. The big advantage of using chlorine is that it is very inexpensive and like most chemical

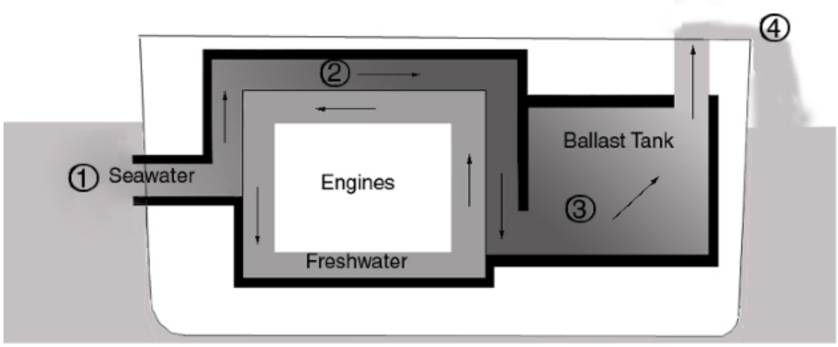


Figure 2.10: 1) Sea water enters the vessel through the sea chest. 2) The water is heated through the freshwater used to cool the vessels' engines. 3) The heated sea water is pumped into the ballast tanks, killing may of the organisms. 4) The treated ballast water is pumped overboard [**?**]. [**?**]

treatment technologies added while loading ballast water and mixed with a mixing device for more efficient treatment. The disadvantage about chlorine is that it is toxic, and cannot be discharged without further neutralization. The other disadvantage about the injection of chlorine is the need for chemical storage on board the vessel.

Chlorine dioxide injection
Chlorine dioxide is different from chlorine. It is an effective oxidant for all aquatic species and widely used around the world for water purification. Contrary to chlorine, chlorine dioxide only reacts with living cells. This makes it a very effective treatment method, especially in high turbidity waters. The other advantage it has compared to electro chlorination, is the fact that at the production only: chlorine dioxide, salt, oxygen and water is produced instead of hydrogen gas.

$$2NaCLO_3 + H_2O_2 + H_2SO_4 \rightarrow 2CLO_2 + Na_2SO_4 + O_2 + 2H_2O \tag{2.3}$$

In this case vessel does not have to store chlorine on board but will have two tanks containing Purate and sulfuric acid [**?**] As the chlorine dioxide is ($\pm$) 2,5 times more effective compared to chlorine, the storage tanks are much smaller. Contrary to chlorine, the effectiveness of chlorine dioxide is relatively unaffected by the pH of the water.

Peracetic acid and hydrogen peroxide
Also works like chlorination. The disadvantage is that high levels of chemicals are needed and thus need proper storage facilities and are rather expensive.

Neutralisation
Neutralization is the process of adding substances to neutralize the ballast water before discharge. This is mostly used after the use of a chemical ballast water treatment method. Depending on the voyage length some chemicals can be degraded before discharging and neutralization products are not necessary. An example of a widely used neutraliser is sodium thiosulphate which neutralizes chlorine.

2.3. Ballast water treatment methods analysis

There are a lot of treatment methods available, all with different pros and cons. All of the available methods are already used on land based applications. The biggest discrepancy lies in the fact that: power supply, time, on-board restrictions of chemicals and available space are limiting factors on-board a vessel. Filtration with a hydrocyclone, coagulation and flocculation seem to be too complex and do not seem suitable for the ballast water treatment application.
Because IMO and USCG regulation originates from an environmental motivation, regular chemicals do not

seem to be a sustainable solution. The fact that extra precautions and regulations apply for the storage of these chemicals on-board a vessel together with the counter intuitive control of the environment with toxic chemicals makes the chemical treatment methods an unlikely solution for this environmental problem on the long term.

The most probable and sustainable solutions seem to be in the physical and mechanical treatment methods. A range of physical methods are either not performing according the USCG and/or IMO standards or too complex and expensive to realize on board a vessel. This would imply that only the UV, electro chlorination and deoxygenation treatment methods seem to be suitable and sustainable options. An overview of all the treatment methods with ratings on different parameters show this in table 2.3.

Treatment method	Environmental friendly	treatment Complexity	Power consumption	Extra regulations (chemicals)	Size	Treatment time
Filtration	++	++	++	++	++	++
Hydrocyclone	++	-	++	++	++	++
Coagulation	+/-	–	+/-	++	+/-	–
Flocculation	+/-	–	+/-	++	+/-	–
UV radiation	++	+	–	++	+	++
Electro chlorination	+/-	+	-	+/-	+/-	++
Deoxygenation	–	–	+	–	+/-	–
Inert gas	–	+	-	+	+	–
Ultrasonic	++	–	-	++	+/-	-
Cavitation	++	–	-	++	+/-	-
Ozonation	–	–	-	+	+	–
Heat	++	++	–	++	–	–
Chlorination	–	+	+	–	+/-	++
Chlorine dioxide	-	+	+	–	+	++
Peracetic acid	–	+	+	–	–	++
Hydrogen peroxide	–	+	+	–	–	++

Table 2.3: Analysis on different ballast water treatment methods.

This table shows the comparison between the different treatment methods in general. Pros and cons can be very dependent on a specific vessel as some vessels have more space where other vessels are not dependent on the treatment time as the vessel only has long voyages.
Considering that every parameter is equally important a score card can be created. These scores are shown in table table 2.4.

Filtration	100%
Hydrocyclone	90%
Coagulation	53%
Flocculation	53%
UV radiation	80%
Electro chlorination	67%
Deoxygenation	37%
Inert gas	53%
Ultrasonic	60%
Cavitation	60%
Ozonation	43%
Heat	60%
Chlorination	60%
Chlorine dioxide	67%
Peracetic acid	53%
Hydrogen peroxide	53%

Table 2.4: Scores of treatment methods based on table 2.3.

3

Important parameters for choosing a ballast water treatment system

In this chapter the important parameters for choosing a ballast water treatment method and system are discussed. Some parameters will be determined by the vessel design while most parameters are influenced by external factors. All these parameters will now be discussed and should be seen as boundary conditions. The most important parameters that are used in the tool are:

- Sailing routes
- Ballast water pump capacity
- Purchase cost, system and installation cost
- Operational costs
- Ballasting profile

When choosing a ballast water treatment system, also the following parameters should be taken into account:

- Salinity of the water
- Temperature of the water
- Turbidity of the water
- Footprint
- Power requirements
- Pressure drops
- Hazardous areas
- Impact of the treatment system on piping and ballast tanks

3.1. Sailing routes

The most important factor whether to install a ballast water treatment system is about the routes that the vessel will sail. The IMO regulation will only be active in the countries that signed the convention and the USCG regulation is only applicable for vessels entering US waters. When a vessel is operating solely between two ports which are located in a so called "SRA same risk area [**?**]" the vessel can get an exemption [**?**] on the regulation [**?**]. This is especially interesting for short sea shipping with a trade between two specific ports. This parameter is not taken into account with the tool calculation. It is assumed that non of the vessels operate solely between same risk areas because the vessels form the NIBC portfolio do not sail on such short routes. The sailing routes also determine the water conditions like temperature and salinity level in different ports. These two parameters are discussed separately.

3.2. Ballast water pump capacity

The ballast water pump capacity of a vessel is one of the most important parameters when considering ballast water treatment solutions. Most treatment solutions treat the ballast water at intake and discharge. The ballast pump capacity of the vessel is dependent on the cargo it carries and the loading capacity of the specific cargo at the terminals as discussed in chapter 2. Because the ballast pump capacity is linked to the cargo loading rate, it is extremely important to ensure full availability of the capacity. When a vessel is not able to perform ballasting at full capacity, the loading rates have to be adjusted. This is a costly action as terminals will only give the vessel a certain timeslot for loading and/or discharging cargo. In case of a delay, caused by the vessel, a fine has to be paid to the terminal. Because full ballast pump capacity is of major importance for the operation in terminals, the capacity of the ballast water treatment system has to match. For the use of the tool, it is assumed that the total ballast water pump capacity at least equals the capacity of the treatment system. When BWT is not performed in-line at the intake and discharge, the total ballast capacity is of importance. Most of the available treatment systems make use on an in-line treatment. This is why the ballast water pump capacity is assumed to be the determining parameter for choosing a ballast water treatment system for the tool.

3.3. Ballasting profile

The ballasting profile of a vessel is the number of ballasting and de-ballasting operations of a full ballast tank. Dependent on the size of the ballast water treatment system and ballast tanks, the the system will operate for a number of hours per year. This is an important parameter because the ballasting profile can push a decision towards buying a system with high capex and low opex or a system with low capex and higher opex. The ballasting profile has the biggest impact on the operational costs. With the ballasting profile of the vessel, the average price per treated m3 water can be calculated. This is an incentive for the ship owner when choosing a ballast water treatment system or alternative solutions like the Damen's Invasave300. For the use of this report a ballasting profile of 50 ballasting cycles is assumed. How this parameter is used in the tool is discussed in chapter 5.

3.4. Purchase cost, system and installation cost

The initial purchase cost of the system itself is an important parameter when considering a ballast water treatment system. Systems with a flow rate of 2,000 m3/h can be priced up to $ 700,000,-, which is a big investment [**?**]. In times where the shipping industry faces low freight rates and owners have large debts, this required investment can have a big impact on the ship owners. The owner needs to have enough cash available for the investment. Budget prices of ballast water treatment systems are provided by different manufacturers. These prices can still vary as prices can be negociated on. This can be the case when the number of orders go up. Prices have fluctuated in the past when in 2017 prices remained stable. In 2017 prices are believed to be low [**?**]. This is caused by the fact barely any systems have been sold over the past, as the convention was not ratified yet. Now that the going into-force date is coming closer, prices are believed to go up again because of the demand.

This research is focused on retrofit installations. This implies that the installation cost has to be considered as well. This is a costly process as the vessel is not designed to fit a BWT system. The installation cost of a ballast water treatment system is dependent on a lot of parameters. Every vessel is different and challenges in the installation process can come up during the process. These uncertainties make the installation cost a parameter, which is difficult to determine. Based on twenty performed retrofits with different flow capacities, ten performed in Europe and then in Asia, an estimation for the installation cost is made for yards in China and Europe [**?**]. From these retrofit projects it can be seen that the installation cost in Europe is approximately 2.5 times more expensive compared to a yard in Asia. This is also an important factor when considering the installation of a ballast water treatment system. These numbers were confirmed by other manufacturers [**?**].

3.5. Operational costs

The operational cost is something to be considered when choosing a ballast water treatment system. For mechanical and physical treatment methods the power supply is the biggest component in the operating costs. Furthermore, the maintenance of the system has to be considered. Ballast water treatment systems using UV technology use lamps which have to be replaced. For EC systems, sensors have to be replaced.

Replacing seperate components is made easy as most manufacturers provide a modulair BWT system. Every component has a different durability which has an impact on the operational costs. The ballasting profile of the vessel contributes to the operational cost as this determines the running hours of the system [**?**].

3.6. Other parameters to be taken into account

3.6.1. Salinity of the water

The salinity of the water in which the vessel operates will depend on the sailing routes. The salinity level of the water is indicated with PSU, the practical salinity unit. For the IMO the salinity levels are divided into three water types:

Name	Salinity level (PSU)
Fresh water	<3
Brackish water	3-32
Marine water	>32

Table 3.1: IMO salinity levels for the three water types [**?**].

The USCG uses different salinity concentrations for the three water types:

Name	Salinity level (PSU)
Fresh water	< 1
Brackish water	10-20
Marine water	28-36

Table 3.2: USCG salinity levels for the three water types [**?**].

Table 3.1 and 3.2 show that the USCG is stricter on the PSU level for fresh water. This implies that when a BWT system is tested for IMO in fresh water, it does not mean that it will perform the same way in fresh water states by the USCG. Different ballast water treatment systems are able to perform in different salinity levels. Especially fresh water can be a challenging environment [**?**]. This problem mainly occurs with systems using the electrochlorination principle. Because salt water is needed for the production of Sodium Hypochlorite, the system will have difficulties operating in fresh waters. This problem could be solved by having a small separate ballast tank filled with marine water. This tank can then be used when ballasting is needed in fresh waters. When a vessel solely operates in fresh water, this can become critical for the system to function. This parameter is not taken into account for the use of the tool. As discussed before, the pricing of an UV or EC system is equal. When the salinity of the water is too low for an EC system to work, the vessels will have to choose for an UV system.

3.6.2. Temperature of the water

The temperature of the seawater changes during the seasons and differs per region. For some treatment methods the temperature influences the functionality. Electro chlorination performance is reduced at temperatures between 10-15 °C and cannot function at temperatures below 5 °C [**?**]. In these cases additional energy is needed to warm up the water at the intake. Some chemicals can also be affected by low temperatures and not function as desired [**?**]. Figure 3.1 shows the average global sea temperatures. When the vessel visits ports in areas with sea temperatures below 15 °C, the performance of the treatment system should be considered.

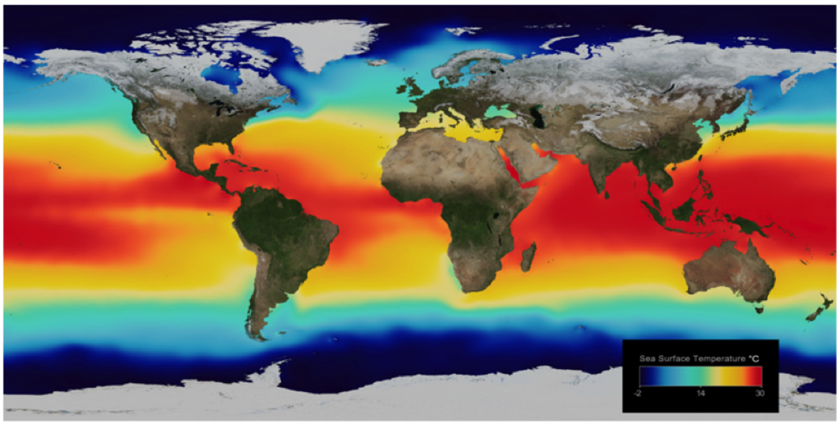


Figure 3.1: Average global sea surface temperatures. Scale in units of degrees Celsius [**?**].

3.6.3. Turbidity of the water

The turbidity of the water is the relative clarity. The turbidity influences the light transmittance of the water [?]. With UV treatment methods, the water should be emitting the ultra violet light in such an extent that the cells are affected. Difference in UV lamps, the configuration and the number of lamps all affect the operational range of the ballast water treatment system. The turbidity is often indicated with the UV transmittance [?], as this is the parameter that influences the UV treatment. Manufacturers claim to be operative in different UVT levels. The turbidity of a specific area is difficult to determine because it is influenced by a lot of external factors. When vessels sail by in shallow waters, sediment comes up, influencing the turbidity and thus the UV transmittance of the water. Also, the tides and seasons influence the turbidity of the water [?]. Table 3.3 shows the nominal turbidities in ports all over the world [?]. Ballast water treatment manufacturers that use UV treatment often show the operability of the system up to a certain UV transmittance. The difficult thing with this number is that the transmittance can be measured at different locations in the system. This can make a big difference. For instance measuring the transmittance level at the sea chest or at the intake of the UV reactor. As in most cases the water has already gone through a filter before entering the UV reactor, the UV transmittance has already gone up. This makes it difficult to analyse whether the treatment system can operate optimally in the different ports shown in Table 3.3. When the vessel solely operates in water with low UV transmittance, the owner should consider a EC system instead.

Port UV-T	(%)	Continent
Yangzte river, Taizhou	37	Asia, China
Lisbon, Portugal	41	Europe
Shanghai, China	49	Asia
Brunswick, GA, USA	51	North America
New Orleans, USA	54	North America
Bremerhaven, Germany	60	Europe
Antwerp, Belgium	66	Europe
Houston, USA	74	North America
Hong Kong, China	80	Asia
Tanjung Pelepas, Malaysia	83	Asia
Zeebrugge, Belgium	85	Europe
Melbourne, Australia	87	Austraila
Wallhamn, Sweden	91	Europe
Brisbane, Australia	92	Austraila
Porto Grande, Cape Verde	92	Africa
Skagen, Denmark	92	Europe
Rotterdam,Netherland	93	Europe
Vera Cruz, Mexico	94	North America
Sankt Augustin, Germany	98	Europe

Table 3.3: Nominal UV transmittance different ports in different continents [?].

3.6.4. Voyage length

The voyage length of the vessel determines the maximum time available for ballast water treatment. When the ballast water is treated at the intake and discharge, species have time to regrow whilst in the ballast tanks. This can influence the quality of the water at discharge. Some ballast water treatment methods that treat the water inside the ballast tanks need a longer treatment period to perform according to the IMO and/or USCG standards. This parameter can exclude some of the available treatment methods as the voyage length of the vessel is too short. Table 3.4 shows an approximate time for the different treatment methods to be effective.

Treatment method	Time to be effective
Chlorine generation	Hours
Chemical application	24 hours
Filtration and UV	At treatment
Deoxygenation	4 to 6 days
Ozone generation	Up to 15 hours

Table 3.4: Approximate time to be effective for different treatment methods [?]

3.6.5. Footprint

The footprint of a ballast water treatment system needs to get proper attention. This report is focused on retrofits in which it is an even more important parameter than with new-build vessels. The available space aboard a vessel is scarce and some treatment methods have a bigger footprint than others. When the ballast capacities increase the required installations increase in size too. This will create a turnover point where some treatment systems become too large to install. This is where other treatment methods will become more interesting just because of their footprint. In most cases the manufacturers will publish the footprint of the system. As an indication the footprint of a 200 m3/h unit can vary between 0.25 and 30 m2 according to the manufacturers [?].

3.6.6. Power requirements

Most ballast water treatment systems need an external power supply. When the ballast pump capacity increases the required power supply also increases. In general it can be said that UV systems require more power than electro chlorination systems with the same flow capacity. The available power supply can be a problem which can result in the need for an additional generator for the BWT system [?].

3.6.7. Pressure drops

When considering a ballast water treatment system one should also take into account pressure drops that occur over the piping of the BWT system. Most of the manufacturers claim pressure drops less than two bar [?]. Pressure drops will occur as treatment systems add resistance to the flow. This especially occurs on retrofits where there is no space designed to fit a BWT system. Multiple bends, significant lengths of piping and valves can cause serious pressure drops [?]. When the pressure drop becomes too large, the system cannot operate under full flow. In a worst case scenario this can result in high flow deviations and results in the ballast pump capacity needing to be upgraded. The ABS states in their Ballast advisory that pressure drops and self cleaning systems can reduce the ballasting time by 20% [1]. Some vessels discharge ballast water from the top tanks through gravity. This can also imply that there is not enough pressure for the ballast water treatment system to work properly.

3.6.8. Hazardous areas

When the BWT system has to be placed in a hazardous area this should be evaluated. Electrical equipment inside hazardous areas like cargo pump rooms in tankers need to be intrinsically-safe. A hazardous area is an area where explosive gases or dust can be expected. There are three levels of hazard danger, all which have their own level of electrical equipment which can be installed [?] to comply with IEC 60092-502. Some treatment manufacturers can provide ATEX approved systems which can be installed in hazardous areas. This will increase the purchase price of the system. The owner should consider moving the installation to a non-hazardous area with the consequence of having to install more piping or to purchase an ATEX approved system.

3.6.9. Impact of the treatment system on piping and ballast tanks

Corrosion of ballast piping and tanks comes with large costs in the vessel's maintenance. A ballast water treatment system could possibly reduce the corrosion rate, resulting in lower overall maintenance costs. On the other hand some treatment systems can even increase the corrosion process resulting in even higher maintenance costs [?]. Chlorine is known to have significant influence on the corrosion process. Ballast water treatment systems using chlorination can thus introduce an even more corrosive environment inside the ballast tanks and piping [?]. Corrosion is an oxidation process. This would imply that deoxygenation methods would reduce the corrosion rate [?]. When oxygen levels are almost zero, an anaerobic type of corrosion can be encouraged. Anaerobic corrosion is a microbiologically influenced corrosion. In marine waters, sulfate reducing bacteria (SRB) is one of the most damaging bacteria accelerating corrosion to the tanks and piping [?].

3.7. Parameter analysis

All the discussed parameters should be thoroughly investigated before choosing a ballast water treatment system. All of the parameters should be considered as boundary conditions. For the use of the tool the most important parameter is the ballast water pump capacity. Also the operating costs are taken into account. This will give an insight on the impact of the ballast water treatment system as it is assumed that the pricing of a BWT system is equal for different methods with the ballast pump capacity range of all NIBC fleet vessels.

[1] It could be that ballasting with some treatment systems with high pressure drops and self-cleaning systems could take 20 percent longer than ballasting without treatment. It should also be noted that at some level of additional system resistance, gravity ballasting may no longer be feasible because the pressure differentials with the sea water are reduced and acceptable flow rates cannot be maintained.[?]"

4

Ballast water treatment systems

The BWM convention will enter into-force on the 8th of September 2017. A list of approved systems is published by the IMO [?]. As of June 2017 the IMO and the issuing administrations approved 69 ballast water treatment systems. Also the US coast guard, following stringent regulations, approved four of these IMO approved systems for the use in US coastal waters as from June 2017. The IMO approved systems vary from well-established systems to basic treatment principles. In chapter 2.2 the different pre-treatment, treatment and neutralizations methods are discussed. In this chapter a selection of well-established treatment systems will be discussed. A selection of ballast water treatment systems and manufacturers will be made which are later used in the tool as described in chapter 7.

4.1. Ballast water treatment methods used for IMO approved BWT systems

As of June 2017, 69 systems have been approved by the IMO. As with every new product that enters the market, a shake-out of manufacturers will take place at the time the regulation will enter into force. Because the convention was originally written in 2004 and will now enter into force in 2017, some manufacturers have already gone bankrupt. For these companies the process of entering into force took too long and too little cash flows forced them to go bankrupt. Based on multiple criteria a prediction of the most probable survivors of this shake-out is made. Important factors for determining these probable survivors are: financial health, size of the company, the ability to provide world-wide service, early USCG type approval, type of treatment. Based on these criteria the discussed treatment systems will be elaborated on. Next to these important criteria, interviews with: Ship owners, classification bureaus, the flag state of the Netherlands, marine-tech institutions and system manufacturers have created a well-informed assessment on probable survivors of the shake out.

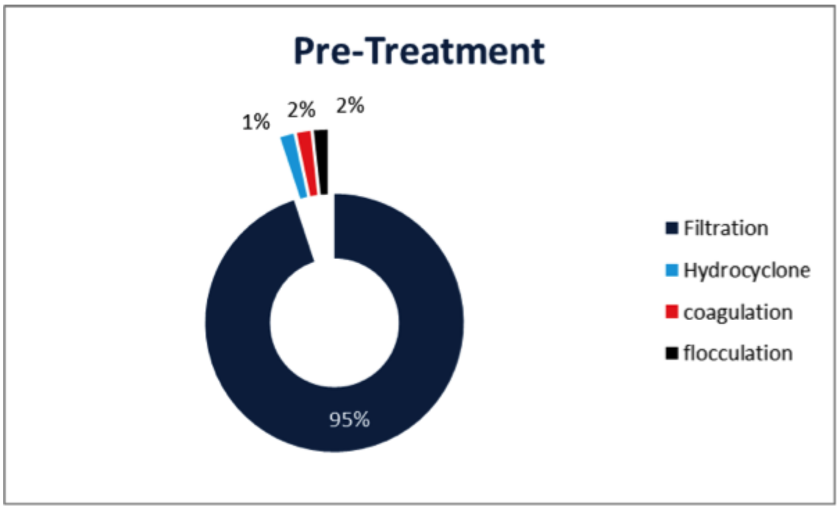


Figure 4.1: Percentages of pre-treatment methods used in IMO approved ballast water management systems.

The systems that have been chosen to be discussed are manufactured by companies that have a strong track record. Most companies are not solely focussed on ballast water treatment systems and already have experience in the marine industry. The fact that customers are familiar with the manufacturer gives them an incentive to do business. The manufacturers are also preferably globally established, providing the customer with worldwide support. The selected companies have completed USCG tests or are planning to do so on short notice.

By analysing the different treatment methods discussed in chapter 2.2, UV treatment and electro chlorination seem to be best. The obtained list of approved systems from the IMO and issuing administrations in June 2017 is categorised by treatment method as mentioned in chapter 2.2. Figure 4.1 shows the categorised system. It can be seen that nearly all ballast water treatment systems make use of filtration in the pre-treatment stage. Filtration is a well-known and robust method which seems best suited for the pre-treatment of ballast water. This is supported by the findings in chapter 2.2. In figure 4.2 it can be seen that the actual treatment methods are more divided, but almost 50% of the approved systems use UV radiation. 17% of the systems make use of electro chlorination.
These two methods are well-established in the market and both make use of relatively simple principles. This is again supported by the findings in chapter 2.2.
UV treatment is a widely used principle for water treatment, ranging from huge drinking water purification plants [**?**] to the treatment of drinking water for the use of dialysis in hospitals [**?**]. Using sodium hypochlorite is a commonly used method for disinfecting public water parks and purification plants [**?**]. The storage of chlorine on a vessel is space-consuming and brings regulations regarding the storage of chemicals. These disadvantages are refuted with an electro chlorination system as no chemical storage is required.

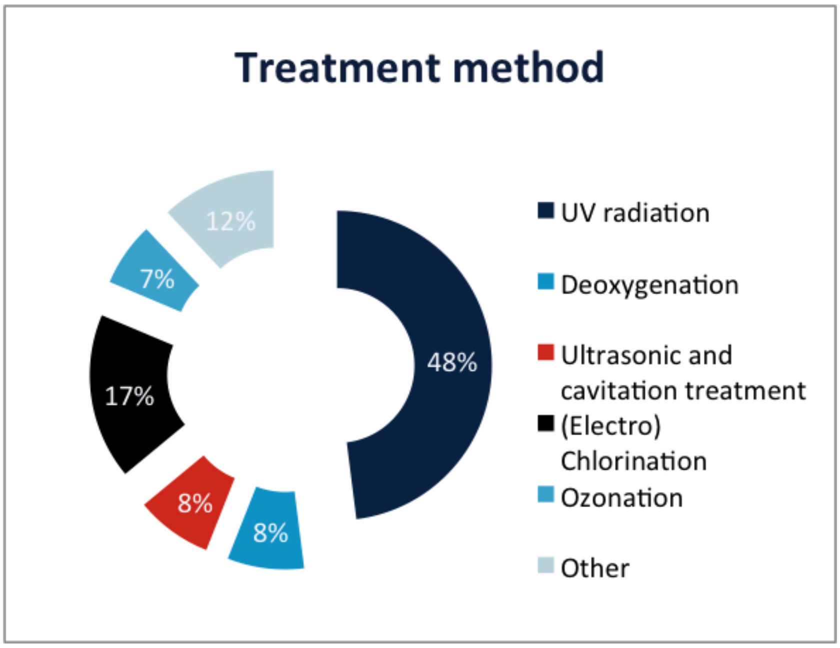


Figure 4.2: Different treatment methods used in IMO approved ballast water management systems.

For both of these methods, ballast water pump capacity is the most important factor because the water is treated in-line at the intake and/or discharge. This becomes a problem when pumping capacities reach over 3,000 m3/h. In this case multiple systems have to be installed. The overall footprint can become too big, especially for a retrofit where the available space is a concern [**?**].
For large bulk carriers and tankers with pump capacities reaching more than 3,000 m3/h a treatment system without a pump capacity restriction is desired. In these cases, deoxygenation treatment could be a good solution. With deoxygenation that uses inert gas, the water is treated in the ballast tanks and thus has no restrictions regarding ballast pump capacity. The fact that deoxygenation treatment needs a long time to be effective makes it unaffective for short voyages. As the larger bulk carriers, tankers and gas carriers usually sail voyages of multiple days [**?**], the deoxygenation treatment could be a suitable solution.

These are the main concerns regarding the predictions on which systems would survive the shake-out and will give a good representation of the available treatment systems. The IMO convention is going to regulate the discharge of the ballast water. This means that it does not force the owner to install a ballast water treatment system. An alternative solutions which does not involve installing a costly system aboard is now available. This solution will also be discussed. The treatment systems and methods discussed in this report are listed in table 4.1.

Treatment system	Manufacturer	Treatment method	Capacity range (m3/h)
PureBallast 3.1	Alfa Laval	Filtration + UV treatment	32 – 3,000
GLD BWTS	ColdHarbour	Inert gas	inf
Balpure	De Nora	Electrochlorination	500 - 20,000
RayClean	Desmi	Electrochlorination	300 – 3,000
Guardian	Hyde marine	Filtration + UV treatment	60 – 3,000
OBS	Optimarin	Filtration + UV treatment	167 – 3,000
GloEn-Patrol	Panasia	Filtration + UV treatment	1,000 - 3,000
Electro-cleen	Techcross	Electrochlorination	150 – 1,000
Aquarius UV	Wärtsilä	Filtration + UV treatment	50 – 1.000
Aquarius EC	Wärtsilä	Electrochlorination	750 – 3,300
Invasave300	Damen	Filtration + UV treatment	300

Table 4.1: Treatment systems, the manufacturer, the method used and the capacity range

4.2. Selection of ballast water treatment systems

In this section, the ballast treatment systems from different manufacturers is shown in table 4.1 will be discussed. First a description of the system is given. Secondly the treatment process will discussed. Ultimately an overview of the company details is given.

4.2.1. PureBallast (Alfa Laval)

The PureBallast 3.1 BWTS, manufactured by Alfa Laval, combines filtration with a basket filter that has UV treatment with medium pressure lamps. This is the third generation of Alfa Laval's ballast water treatment technology. Its modular build-up makes it possible to deliver 12 treatment configurations in one installation. Further extension of the system can be done by linking multiple systems. The main set-up consists of five components: A basket filter, a reactor, a lamp drive cabinet, a control cabinet and a CIP cleaning-in-place unit [**?**]. This system has both IMO and USCG approval. Figure 4.3 shows a visualisation of the ballast water treatment system.

Figure 4.3: Pureballast ballast water treatment system from Alfa Laval [**?**]

Based on the parameters discussed in chapter 3 a fact sheet with basic parameter evaluations is shown in table 4.2.

Parameter	Value	range
Flow rates	(m3/h)	32 – 3,000
Footprints	(kg)	1,200 – 4,665
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	(42 / 65)
Treatment duration	(hours)	Instant
Power consumption	(kW)	17 – 300
ATEX system available	(yes/no)	Yes

Table 4.2: Basic parameters. Footprint including: Reactors, filters, CIP, lamp drive cabinet and control cabinet. [**?**]

The system treats the water at intake through the basket filter, followed by the UV reactor with medium pressure lamps. At discharge, the water flows through the reactor again to reduce the number of needed UV lamps. The system can operate in fresh, brackish and marine waters and operates in liquid water with frigid temperatures. With the medium pressure lamps installed, the system is able to operate in low clarity waters until 42% UV transmittance under full flow for IMO approval. Conform USCG standards the system can operate at full flow with UV transmittance of 65%. At half the flowrate the system can operate in waters with a UV transmittance of 55% [**?**]. As the system is installed in line with the ballast water piping, the footprint is relatively small [**?**].

Company details
As Alfa Laval is a well-established globally operating listed company with annual order intake of more than $ 3.5 Billion in 2016, ship owners can expect worldwide ownership support in almost 100 countries [**?**]. Spare parts and service will be available on a global scale [**?**]. The fact that Alfa Laval is not solely dependent on its

ballast water treatment systems and the long lasting history of the company, makes the company a reliable and proven service partner. The ballast water treatment solution from Alfa Laval is part of the "Marine & Diesel division". The Marine and diesel division covers more than $ 993 Million on orders intake of which % 22, almost $ 220 Million on "Marine & Diesel equipment" [**?**]. The ballast water treatment equipment is part of this "Marine & Diesel equipment" division [**?**].

4.2.2. GLD BWTS (ColdHarbour marine)

The GLD BWTS, manufactured by ColdHarbour, uses deoxygenation with inert gas as a ballast water treatment method. This system is independent of the ballast pump capacity as treats the water inside the ballast water tanks. This makes the treatment method interesting for ULCC/VLCC tankers with large tank and pump capacities [**?**]. The GLD BWTS is approved by the IMO. Figure 4.4 shows a visualisation of the ballast water treatment system.

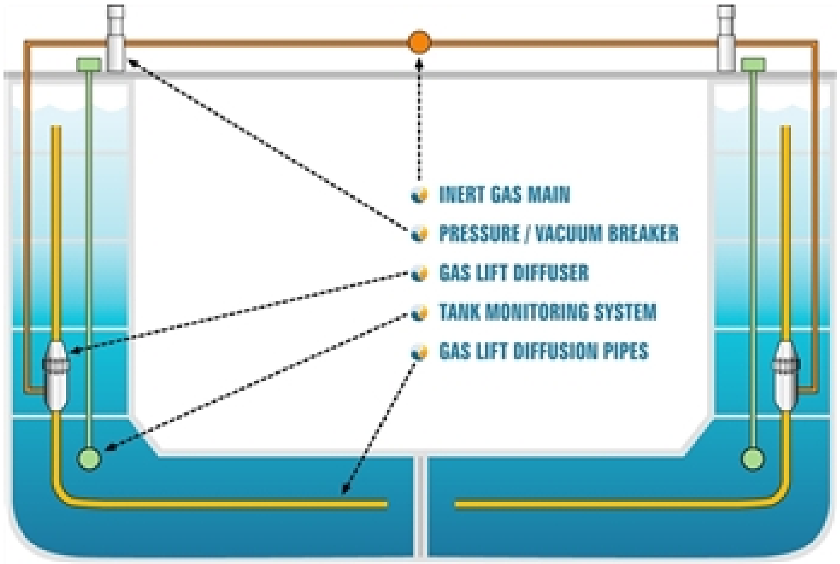


Figure 4.4: GLD the inert gas ballast water treatment solution from Colharbour marine [**?**]

Parameter	Value	range
Flow rates	(m3/h)	1,600 - 6,000
Footprints	(kg)	Dependent on number of ballast tanks
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	Independent
Treatment duration	(hours)	5 days +
Power consumption	(kW)	240 - 473
ATEX system available	(yes/no)	No

The system uses the inert gas output from the inert gas generator (IGG). The inert gas is then diffused through a specially designed *"Gas Lift Diffusion (GLD) pipe"* inside the ballast water tanks. The oxygen in the tank is stripped and the pH level is temporarily lowered. This creates an environment where aerobic and anaerobic species can not survive.
The big advantage of using inert gas is the fact that it is independent on the ballast water pump capacity. This ensures the full capacity of the ballast pumps at any time. The disadvantage is the long treatment time and the high purchase cost.

Company details
Coldharbour marine is a UK based company with more than 35 years of experience in marine and offshore product design. With offices in 13 countries, it is a well-established company where global ownership support can be expected.

4.2.3. Balpure (De Nora)

The Balpure BWTS, manufactured by De Nora, makes use of and electro-chlorination unit to treat the ballast water. The Balpure system uses a 1% slip stream which makes it possible to install the system away from the main ballast line when the available space is limited. The Balpure system is approved by the IMO. Figure 4.5 shows a visualisation of the ballast water treatment system.

Figure 4.5: Balpure ballast water treatment system from De Nora [?]

Parameter	Value	range
Flow rates	(m3/h)	500 – 20,000
Footprints	(m3)	Not disclosed
Operates in salinity level	(PSU)	Not disclosed
Full flow in UVT level (IMO / USCG)	(%)	(Independent)
Treatment duration	(hours)	Hours
Power consumption	(kW)	Not disclosed
ATEX system available	(yes/no)	Not disclosed

The system treats the water at intake through a filter. At the same time, a 0.5 to 1% slipstream of the entire ballast water flow is fed to the electrolyzer. Hypochlorite is created from the slipstream of the sea water within a minute. The hydrogen, which comes as a by-product, is passed to a de-separator, diluted with air and safely vented to the atmosphere. The slipstream with hypochlorite and seawater is then mixed into the main ballast flow [?]. It is then pumped into the ballast tanks where a residual amount of hypochlorite prevents regrowth of organisms inside the tanks. At discharge, the filter is bypassed and injected with sodium bi-sulphate which acts like a neutraliser. The water is then discharged according to the IMO regulations [?].
The system operates in marine, brackish and fresh water. The "De Nora" slip stream technology allows operation in low salinity and low temperature waters.

Company details
De Nora, active since 1923 is an electrochemistry specialist. The India listed company had a revenue of almost $ 8.5 Million in 2016 [?]. The company started in 2004 with the research and manufacturing of the ballast water treatment system. In 2010 their Balpure system received IMO approval. With 12 manufacturing plants and a a total of 29 offices around the world, it is a well-established company where global ownership support can be expected [?]. The fact that De Nora does not solely depend on its ballast water treatment systems

makes the company a reliable manufacturer and service partner. The fact that De Nora has a long record in electrochemistry is a big advantage.

4.2.4. RayClean (Desmi)

The RayClean BWTS, manufactured by Desmi, makes use of a 50 micron filter and a low pressure UV unit. The rayclean technology offers 300 m3/h reactors which can be installed in parallel to facilitate a treatment capacity of 3,000 m3/h. The main set-up consists of four components: a filter unit, UV units, UV control panels and main control panels [?]. The Rayclean system is IMO approved. Figure 4.6 shows a visualisation of the ballast water treatment system.

Figure 4.6: RayClean ballast water treatment system from Desmi [?]

Parameter	Value	range
Parameter	Value	range
Flow rates	(m3/h)	100 – 3,000
Footprints	(kg)	1,425 – 11,975
Operates in salinity level	(PSU)	Independent
Full flow in UVT level(IMO / USCG)	(%)	(55% / Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	22 – 220
ATEX system available	(yes/no)	No

The system will treat the water through the filter with automatic backflush whereafter it passes through the UV unit. Because the system is using low pressure UV lamps, the warm-up procedure will only take around one minute and energy consumption is low. After ballasting the system will start an automatic mechanical cleaning procedure to clean the UV unit. At discharge the water will go through the mesh filter again to make sure that the organisms small enough to pass the filter at uptake will be stopped. After a second UV treatment, the water is discharged and complies with the IMO regulations [?]. Because Desmi makes use of low pressure UV lamps, the footprint will be large. More UV lamps mean that more space is needed to comply with the IMO regulation.
As UV treatment is independent to salinity it can operate in marine, brackish and fresh waters. Water with temperatures lower than 0 degrees but in fluid form can be treated.

Company details
Desmi is a private company with more than 180 years of experience with marine pump equipment. The company had a total revenue of more than $ 124 Million [?] in 2015. With offices all over the world, it is a well-established company where global ownership support can be expected. The fact that Desmi is not solely dependent on its ballast water treatment systems together with the long lasting history of the company, makes it a reliable and proven service partner.

4.2.5. Guardian Gold (Hyde marine)

The Guardian BWTS, manufactured by Hyde marine, makes use of a highly effective screen filter and a medium pressure UV chamber. Hyde marine offers ballast water treatment systems in 15 different configurations. Systems can be placed in parallel to provide treatment of up to 6,000 m3/h. The main set-up consists of five components: a filter unit, UV chamber(s), control panel(s), power panel(s) and for the systems up to a flow capacity of 300 m3/h, a backflush pump [?] [?]. The Guardian Gold BWT system is approved by the IMO. Figure 4.7 shows a visualisation of the ballast water treatment system.

Figure 4.7: Guardian Gold ballast water treatment system from Hyde Marine [?]

Parameter	Value	range
Flow rates	(m3/h)	60 – 3,000
Footprints	(kg)	403 – 13,980
Operates in salinity level	(PSU)	Independent
Full flow in UVT level	(IMO / USCG)	(%) (70 / Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	10 – 228
ATEX system available	(yes/no)	Yes

The system treats the water through a 40 micron screen filter with automatic backflush where-after it passes through the UV chamber. The highly effective screen filter introduces a reduction of 50% in footprint compared to other filters[?]. The medium pressure UV lamps contain a quartz sleeve which is automatically wiped to prevent the accumulation of dirt. At discharge the water will bypass the filtration unit and flows through the UV chamber for a final treatment where-after it is discharged according to the IMO regulations. Because UV treatment is independent to the salinity level, it is able to operate in marine, brackish and fresh waters. Water at temperatures lower than 0 degrees but in fluid form can be treated.

Company details

Hyde Marine traces its origins to the Hyde Windlass company founded in 1865 and is part of CalgonCarbon technologies. CalgonCarbon is a well-established company with net sales of more than $ 510 Million in 2016 [?]. The reliable and respectable marine equipment supplier started more than 25 years ago with the use of UV technologies. The technology was widely used for: disinfecting drinking water, industrial waste water and re-mediating contaminated water. With service centres in more than ten countries, it is a well-established company where global ownership support can be expected. The fact that Hyde marine is a CalgonCarbon company, focussed on air and water purification, that does not solely depend on its ballast water treatment systems together with its long lasting history makes the company a reliable manufacturer and service partner.

4.2.6. OBS Optimarin Ballast System (Optimarin)

The OBS BWTS, manufactured by Optimarin, makes use of three different 40 micron filters and single medium pressure UV chambers. Optimarin offers ballast water treatment systems in 18 different configurations. Systems can be installed with 18 UV chambers to provide treatment up to 3,000 m3/h. The main set-up consists of four components: a filter unit, UV chamber(s), control panel(s) and power panel(s) [**?**]. The OBS BWTS is both IMO and USCG approved. Figure 4.8 shows a visualisation of the ballast water treatment system.

Figure 4.8: 3D drawing of a 500 m3/h UV ballast water treatment system from Optimarin. [**?**]

Parameter	Value	range
Flow rates	(m3/h)	167 – 3,000
Footprints	(m3)	2.29 – 12.9
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	(Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	40 – 720
ATEX system available	(yes/no)	Yes

The system will treat the water through one of the 40 micron filters with automatic backflush whereafter it passes through the UV chamber. The Boll & Kirch candle type filter is the only filter that can be used for USCG type approval. The medium pressure UV lamps are self-cleaning without any moving parts and chemicals. At discharge the water will bypass the filter and flows through the UV chamber(s) for a final treatment whereafter it is discharged according to the IMO and USCG regulations.
As UV treatment is independent to the salinity level, it can operate in marine, brackish and fresh waters. Water at temperatures lower than 0 degrees but in fluid form can also be treated.

Company details
Optimarin AS was found in 1994 as one of the first companies to develop ballast water purification systems. The 2016 turnover of Optimarin AS was valued at $ 9.4 Million. Torvald Klaveness as main shareholder with a turnover of $ 262 Million, is a solid backbone of Optimarin [**?**]. With six offices spread around the world it strives to be a global product provider. Optimarin will also act like a service provider. The OBS system was the first to receive USCG type approval.

4.2.7. GloEn-Patrol (Panasia)

The GloEn-Patrol BWTS, manufactured by Panasia, uses a 50 micron filter and a medium pressure UV unit. Panasia offers ballast water treatment systems in 9 different configurations. The main set-up consists of four components: a filter unit, UV chamber(s), control panel(s) and power panel(s) [?]. Figure 4.9 shows a visualisation of the ballast water treatment system.

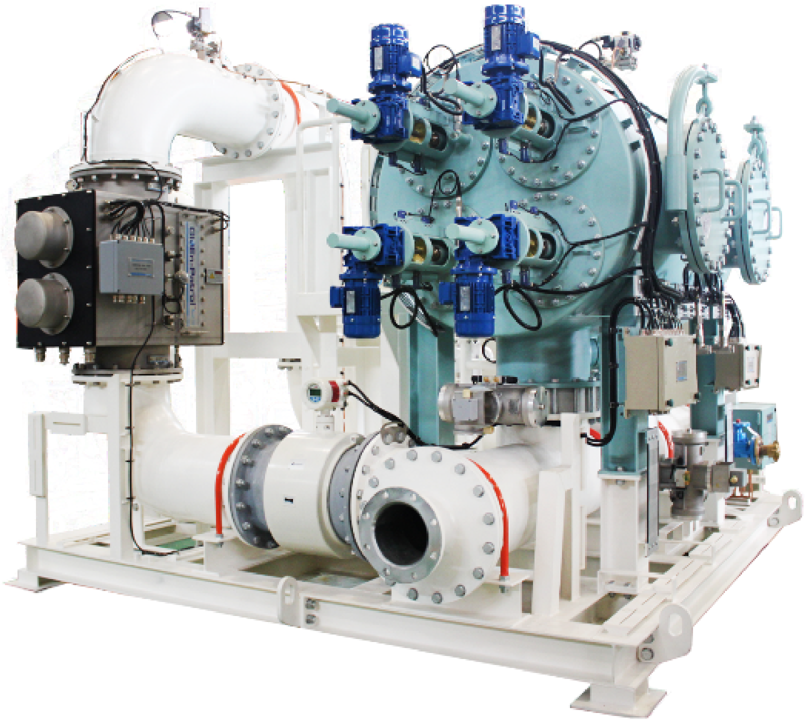


Figure 4.9: GloEn-Patrol II ballast water treatment system from Panasia [?]

Parameter	Value	range
Flow rates	(m3/h)	1,000 – 3,000
Footprints	(kg)	Not disclosed
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	(80 / Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	70 – 225
ATEX system available	(yes/no)	Yes

The system treats the water through a 50 micron filter with automatic backflush where-after it passes through an UV chamber. The medium pressure UV lamps are self-cleaning by a wiper's back and forth movement. At discharge the water will bypass the filter and flow through the UV chamber for a final treatment.
Because UV treatment is independent to the salinity level it is able to operate in marine, brackish and fresh water. Water at temperatures lower than 0 degrees but in fluid form can also be treated.

Company details
Panasia was established in 1989 as an engineering company which produced measuring instruments of shipbuilding and industrial equipment. Because of the company's competence it is to become the leading company managing water & air purification control. With spare supply centres in 15 countries and a global service network in 30 countries, it is a well-established company where global ownership support can be expected. The fact that Panasia does not solely depend on its ballast water treatment systems makes the company a reliable manufacturer and service partner.

4.2.8. Electro-Cleen (Techcross)

The Electro Cleen BWTS, manufactured by Techcross, makes use of a 3 mm mesh filter and an electro chlorination unit. The Aquarius has a modular build-up making it possible to deliver 16 different treatment configurations. Further extension of the system is realised by installing multiple systems for flow rates reaching more than 10,000 m3/h. The main set-up consists of six components: a T strainer, an ECU (electro chamber unit), a PDE unit (power distribution equipment), an ANU (auto neutralization unit), TSU (TRO sensor unit) and a CPC (control PC & S/W) [**?**]. The Electro-cleen system is IMO approved. Figure 4.10 shows a visualisation of the ballast water treatment system.

Figure 4.10: Electro-Cleen ballast water treatment system from Techcross [**?**]

Parameter	Value	range
Flow rates	(m3/h)	150 – 6,000
Footprints	(kg)	1,007 – 11,940
Operates in salinity level	(PSU)	1 PSU
Full flow in UVT level (IMO / USCG)	(%)	(Independent)
Treatment duration	(hours)	Hours
Power consumption	(kW)	X – 92
ATEX system available	(yes/no)	Yes

The system treats the water at intake through a 3mm filter to take out very large particles, whereafter it will pass through the electro chamber unit. Hypochlorite is created from the sea water and pumped into the ballast tanks. At discharge, the filter is bypassed and goes directly to the auto neutralization unit where the water is neutralised according to the data received from the Flow meter unit and the TRO sensor unit.
In marine waters with a salinity of at least 30 PSU the system will operate most efficiently. At lower salinity levels of up to 1 PSU, the power consumption is almost multiplied by three [**?**]. Because the Techchross system does not use fine mesh filters, it is able to operate in frigid water temperatures up to -1,8 ° C. This is an advantage compared to systems using fine mesh filters where Ice slushing will block the filters.

Company details
Techcross is a company established in 2,000 that focusses only on ballast water treatment. With offices in the USA, the Netherlands, China, Korea, Singapore and service stations in more than nine countries it has established a global network. It is part of an alliance with the listed Bubang holdings. Bubang is a Korean holding company with annual net sales of almost $ 122 Billion [**?**] in 2015. Techcross, backed by Bubang holdings can be considered a serious option with long lasting service support. Techcross states to be the ballast water treatment solution for all flow capacities ranging from 150 up to 6,000 m3/h [**?**].

4.2.9. Aquarius-UV and Aquarius-EC BWTS (Wärtsilä)

Aquarius-UV
The Aquarius-UV BWTS, manufactured by Wärtsila, combines filtration with a 40 micron filter that has UV treatment with low pressure lamps. This system contains an integrated antifouling control system which means no separate CIP unit is needed. The Aquarius has a modular build-up making it possible to deliver 13 different treatment configurations with three reactor sizes and four filter sizes. Further extension of the system can be done by installing multiple systems in parallel up to 6,000 m3/h. The main set-up consists of four components: A filter, a reactor, a lamp drive cabinet and a control cabinet [?]. The Aquarius-UV BWTS is IMO approved.Figure 4.11 shows a visualisation of the Aquarius-UV BWTS.

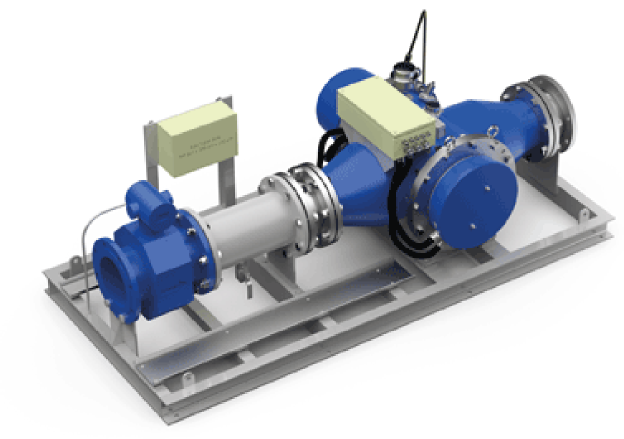


Figure 4.11: Aquarius-UV ballast water treatment system from Wärtsilä [?]

Parameter	Value	range
Flow rates	(m3/h)	50 – 3,000
Footprints	(kg)	935 – 12,825
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	(Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	19 – 100
ATEX system available	(yes/no)	Yes

The system treats the water at intake through the filter, followed by the UV reactor with low pressure lamps. At discharge, the filter is bypassed but the water will go through the UV reactor for a final treatment. The system can operate in fresh, brackish and marine waters as the treatment method is not influenced by the water salinity. Wärtsilä does not disclose any data on the UV transmittance in which the system can operate in full flow. The company states that UV transmittance is measured at different locations in the treatment system which makes it an unreliable parameter for comparing different systems which could be suitable for different water types [?].

Aquarius-EC BWTS (Wärtsilä)
The Aquarius-EC BWTS, manufactured by Wärtsila, combines filtration with a 40 micron filter that has an electro chlorination module. The Aquarius has a modular build-up making it possible to deliver 16 different treatment configurations. Further extension of the system can be done by installing multiple systems to reach flow rates up to 13,200 m3/h. The main set-up consists of seven components: A filter, an EC cell module, a side stream module, a dosing/degassing module, a mixer module, a neutralisation module and a control cabinet [?]. The Aquarius-EC BWTS is IMO approved. Figure 4.12 shows a visualisation of the ballast water treatment system.

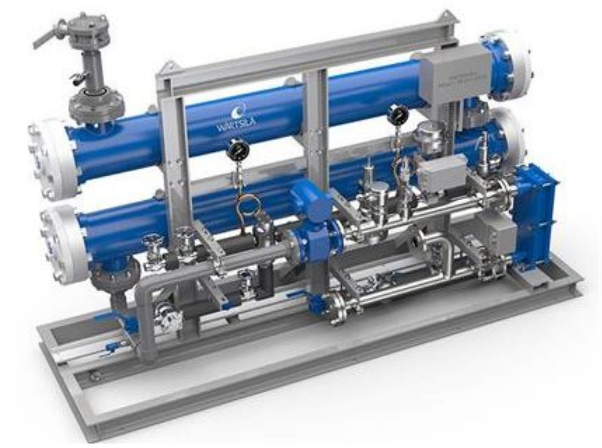


Figure 4.12: Aquarius-EC ballast water treatment system from Wärtsilä [?]

Parameter	Value	range
Flow rates	(m3/h)	750 – 3,600
Footprints	(kg)	8,500 – 12,066
Operates in salinity level	(PSU)	Independent (Salt water tank)
Full flow in UVT level (IMO / USCG)	(%)	(Independent)
Treatment duration	(hours)	Hours
Power consumption	(kW)	60.6 – 365.5
ATEX system available	(yes/no)	Yes

The system treats the water at intake through the filter, followed by the side stream electro chlorination cell. Hypochlorite is created in the side stream from the sea water and pumped into the main ballast line. The proper disinfection mixture is then pumped into the ballast tanks. Three TRO (Total Residual Oxygen) sensors ensure a redundant monitoring of the correct hypochlorite dosing. At discharge, the filter is bypassed and with the use of TRO sensors the required neutralizing sodium bisulfite is added [?].
The system can operate in marine and brackish water. In fresh water it makes use of an on-board storage tank with marine water. This storage tank can be loaded when the vessel is sailing in marine waters. Wärtsilä makes use of a side-stream electro chlorination module which requires less marine water to treat all ballast water.

Company details
Wärtsilä is a well-established global listed company with annual net sales of almost $ 5.1 Billion in 2016. Ship owners can expect worldwide ownership support. Spare parts and service will be available on a global scale with offices in more than 70 countries worldwide. The fact that Wärtsilä is not solely dependent on its ballast water treatment systems and the long lasting history of the company, makes the company a reliable and proven service partner. The fact that Wärtsilä manufactures both UV and electro chlorination systems, gives them a knowledge advantage. The company knows pros and cons of both systems and can provide the best suitable solution for the customer. Wärtsilä also offers the owner a full service installation with a completion time of around 8 to 10 months. Because the company has licensee contracts for almost all components, it is expected that no delivery problems will occur during the expected rush on ballast water treatment systems in the coming years. The marine solution division of Wärtsilä covers 35% of the net sales with more than $ 1.7 Billion. The ballast water treatment systems is part of this marine solution division.

4.2.10. Invasave 300 (Damen)

The Invasave 300 port solution, manufactured by Damen, is an alternative solution to comply with the IMO regulation. Damen produced a mobile ballast water treatment technology with a pump capacity of 300 m3/h inside a 45 foot container. This solution does not require any installation cost for the ship owner [?]. Figure 4.13 shows a visualisation of the ballast water treatment system.

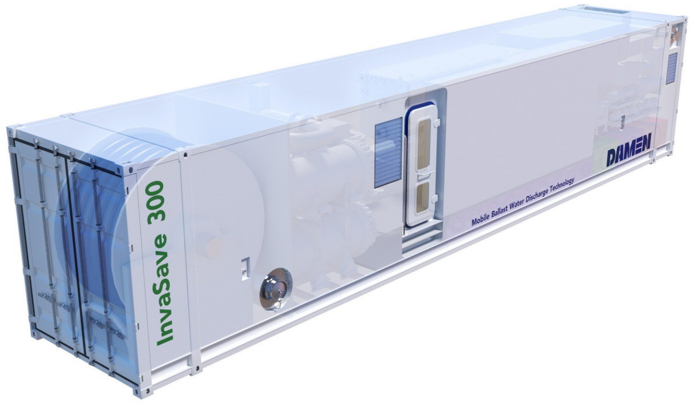


Figure 4.13: Invasave 300, the portable ballast water treatment system from Damen [?]

Parameter	Value	range
Flow rates	(m3/h)	300 - ∞
Footprints	(kg)	0
Operates in salinity level	(PSU)	Independent
Full flow in UVT level (IMO / USCG)	(%)	(Not disclosed)
Treatment duration	(hours)	Instant
Power consumption	(kW)	0
ATEX system available	(yes/no)	No, not required

This solution can be used both as a back-up and an alternative treatment solution. The Invasave can be used to treat up to 300 m3/h per container. Multiple containers can be placed in parallel to treat with higher flow rates. Other options would be for service providers to receive the water in a separate tank whereafter it is being filtered with 300 m3/h [?].
The system is able to operate in marine, brackish and fresh waters. Water at temperatures lower than 0 degrees but in fluid form can be treated as well.
Because this new solution is not offered in all ports in the world together with the uncertainty of the pricing, this alternative solution is not considered for NIBC's portfolio. This could be a good back-up solutions for the event where the BWT system on board the vessel is malfunctioning. This is why there is also no cost study performed for this BWT system.

Company details
Damen is an international shipyard group founded in 1922. Damen builds vessels for all different purposes. With yards and service centres all over the world, Damen is a well-established company where global ownership and service support can be expected. Damen, with a turnover of $ 2.2 Billion in 2016, will only produce the Invasave but not operate it. This will be done by separate service providers. The service providers will be the companies working with ship owners.

4.3. Treatment solution comparison

This section will make a comparison of the technical specifications of the different ballast water treatment systems. Every ship owner should review its vessel and consider all parameters that are of importance as

discussed in chapter 3 before choosing a BWTS. The fit of a ballast water treatment installation is so specific that no clear statement can be made on which system is superior to the others. Every single parameter should be discussed to come up with a best fit.
Some manufacturers will provide a smaller footprint but the composition of the different parts can make the difference whether the system fits or not. This problem characterizes the overall issue of choosing a best fit ballast water treatment product. Two parameters are specifically chosen to make a comparison between the discussed manufacturers, the footprint volume and the power consumption. The footprint is expressed in total m3 because this leaves out the composition of the components. The other parameter discussed is the power consumption which is expressed in kWh/m3. Different manufacturers offer different sizes and compositions as discussed in the previous chapter. This makes it hard to compare one to the other. To make a comparison, the ballast water pump capacities are placed into six size buckets. The following buckets of capacity ranges are used:

- 50 - 500 m3/h
- 501 - 1,000 m3/h
- 1,001 - 1,500 m3/h
- 1,501 - 2,000 m3/h
- 2,001 - 3,000 m3/h
- 3,001 - 6,400 m3/h

When the capacity increases, the volume, weight and power consumption will increase too. To equalise the capacity factor, all the parameters are divided by the capacity. This will give the $\frac{m3}{(\frac{m3}{h})}$ and the $\frac{kW}{(\frac{m3}{h})}$. The findings in these buckets will be discussed in section 4.3.1.

4.3.1. Footprint volume and power consumption

This section is an analysis of the footprint and power consumption of all the discussed BWTS. The footprint is expressed in volume and the power consumption in kWh. The power consumption will show the total maximum power requirement for the operation of the BWTS. This section will briefly discuss the six capacity buckets. The actual figures can be found in appendix B.

50 to 500 m3/h
For the 50 to 500 m3/h range, the Alfa Laval UV system [**?**] shows the smallest footprint per m3 of pump capacity. The 300 m3/h system from Alfa Laval is a very compact system. The Techcross EC systems can also be considered small for their capacity. The Wärtsila UV system turns out to be the largest in the capacity range between 50 and 500 m3/h. The actual figures can be found in Appendix B in table B.1.
The Techcross system performs best according to kWh/m3 ballast water treated. When comparing the installed power between an UV system and an EC system they are almost identical. The fact that a UV system needs to treat the water twice, at intake and at discharge, makes it a method which consumes almost twice as much compared to a EC system. The actual figures can be found in Appendix B in table B.2.

500 to 1,000 m3/h
For the 500 to 1,000 m3/h range, the Alfa Laval system has the smallest footprint per m3 pump capacity again. The behaviour that is seen in table B.1 is reflecting the same way on the 500 to 1,000 m3/h systems.
Here the Wärtsila EC system shows the best results based on kWh/m3 followed by the Techcross EC system. Alfa Laval scores average whereas the Optimarin and Wärtsila UV system show high consumption rates. The actual figures can be found in appendix B in table B.3 and B.4.

1,000 to 1,500 m3/h
The systems ranging between 1,000 and 1,500 m3/h show that the Hyde marine and Optimarin systems are performing the best according to the volume. The Wärtsila EC system shows the largest footprint in this range.
Again that the Wärtsila EC system performs the best when looking at the power consumption. The DESMI system which makes use of low-pressure lamps that consume less energy comes in second place. The actual figures can be found in appendix B in table B.5 and B.6.

1,500 to 2,000 m3/h
For the range between 1,500 and 2,000 m3/h, the Techcross EC system shows the smallest footprint. Again the Wärtsila EC system shows the largest footprint.
The Wärtsila EC system shows the largest footprint, followed by the Techcross EC system which only consumes 10% more. For this pump capacity range, it can be said that when looking purely to the footprint and power consumption, the Techcross EC system comes out best. For these larger pump capacities, the EC systems seem to come out better compared to the UV systems. The Wärtsila EC system scores high with the low power consumption but the voluminous system shows a disadvantage compared to Techcross. The actual figures can be found in appendix B in table B.7 and B.8.

2,000 to 3,000 m3/h
In the range between 2,000 and 3,000 m3/h the Techcross EC system has the smallest footprint again. The Inert gas system from ColdHarbour also shows good results. The Wärtsila EC system turns out to be the largest in this range.
The two Wärtsila EC systems have the smallest power consumption. The Techcross EC system comes in third for this capacity range. The actual figures can be found in appendix B in table B.9 and B.10.

3,000 to 6,000 m3/h
For the largest pump capacities, between 3,000 and 6,000 m3/h it is clear that the Inert gas system takes first place for both footprint and power consumption. The actual figures can be found in appendix B in table B.11 and B.12.

5 Cost analysis ballast water treatment systems

This chapter is about the cost analysis of the ballast water treatment systems. To gain insight on the impact of the ballast water management convention, a cost analysis on ballast water treatment systems is performed. As discussed in chapter 4 there are multiple ways to comply with the ballast water management convention. The most obvious solution is the installation of a ballast water treatment system. In this research it is assumed that no alternative solution is analysed because it does not seem to be a good solution for NIBC's portfolio, as discussed in chapter 4. The cost analysis covers the purchase cost, installation cost and operational expenses for all the treatment systems discussed in chapter 4. The cost analysis is used in the tool described in chapter 7.

5.1. Purchase cost

The purchase cost of a ballast water treatment system is seen as a separate cost component. Most ballast water treatment manufacturers do not have their own repair yard to install a system. While most manufacturers will offer a turn-key solution in collaboration with the yards, the pricing will be separate. For the cost analysis 11 different systems, three of which are ATEX approved, are used. Table 5.1 shows the treatment technology, manufacturer and ballast water pump capacity which are used for the analysis.

Treatment method	Manufacturer	Ballast water pump capacities (m3/h)
UV	Wärtsilä	(250; 500; 1,000; 1,500; 2,000; 3,000)
UV ATEX	Wärtsilä	(500; 1000)
EC	Wärtsilä	(500; 1,000; 1,500; 2,000; 2,500; 3,000)
EC ATEX	Wärtsilä	(500; 1,000; 1,500; 2,000; 1,500; 3,000)
EC	De Nora	(1,500; 2,000)
EC	Techcross	(150; 600; 1,000; 1,600; 2,000; 2,500; 3,000)
UV	Alfa Laval	(170; 300; 500; 600; 750; 1,000; 1,200; 1,500; 2,000; 3,000)
UV	DESMI	(300; 600; 900; 1,200)
UV	Hyde marine	(60; 100; 150; 250; 300; 450; 500; 600; 700; 1,000; 1,250; 1,500; 2,000; 2,500; 3,000; 4,000; 5,000; 6,000)
UV ATEX	Hyde marine	(60; 100; 150; 250; 300; 450; 500; 600; 700; 1,000; 1,250; 1,500; 2,000; 2,500; 3,000; 4,000; 5,000; 6,000)
Inert gas	Coldharbour	(1,600; 2,400; 2,400; 3,400; 5,000; 5,400; 5,600; 6,000; 6,400; 7,200)

Table 5.1: Treatment methods and manufacturers used for a cost analysis which is used in the tool 7.

This makes a total of 89 different systems of which the pricing is known as from February 2017. The prices are based on real offers to ship owners who will not be specified [**?**] [**?**] [**?**] [**?**] [**?**] [**?**].

When comparing the purchase price of each system a clear linear relation can be found between all the UV and EC ballast water treatment methods, as shown in figure **??**. Prices only vary a little regarding size, method and manufacturer. On average both the UV and EC BWT systems can be bought at the same price at different flow capacities. For other solutions like an inert gas installation, prices are much higher. This only seems a favorable solution when the ballast water pump capacity exceeds 3,000 m3/h. At this point the voluminous UV and EC systems can become too large to fit on the vessel. Note that the given prices are indications, prices may vary for each individual order. Multiple orders at once can drive the price down [**?**].
FIGURE NOT SHOWN DUE TO CONFIDENTIALITY REASONS

5.2. Installation cost

The engineering and installation of the ballast water treatment system is the biggest cost factor next to the purchase cost. For EC systems ranging upto 3,000 m3/h the installation prices of performed installation projects are known. The engineering cost is set at $ 2,100 independent of the size of the system [**?**] and based on European prices. The engineering cost is assumed to be the same for all vessels because the seagoing vesssels that are analysed in this report carry the same number of pumps. The prices of the installation cost are given for a Chinese yard. It is assumed that prices for installation in European yards are 2.5 times higher compared to Chinese yards [**?**]. It is also assumed that the engineering and installation cost of a UV system is equal to the cost of an EC system. This is assumed as these systems almost have the same size and both work in-line with the ballast water piping. The engineering and installation cost can be shown as a percentage of the purchase costs. By interpolating between the 7 known costs, a cost estimation on every ballast water pump capacity can be made. This is shown in figure 5.1. These prices are used for the engineering and installation cost for each system ranging upto 3,000 m3/h. It has to be noted that these prices are based on engineering and installation without any big complications that could delay the installation and cause a large increase in costs.

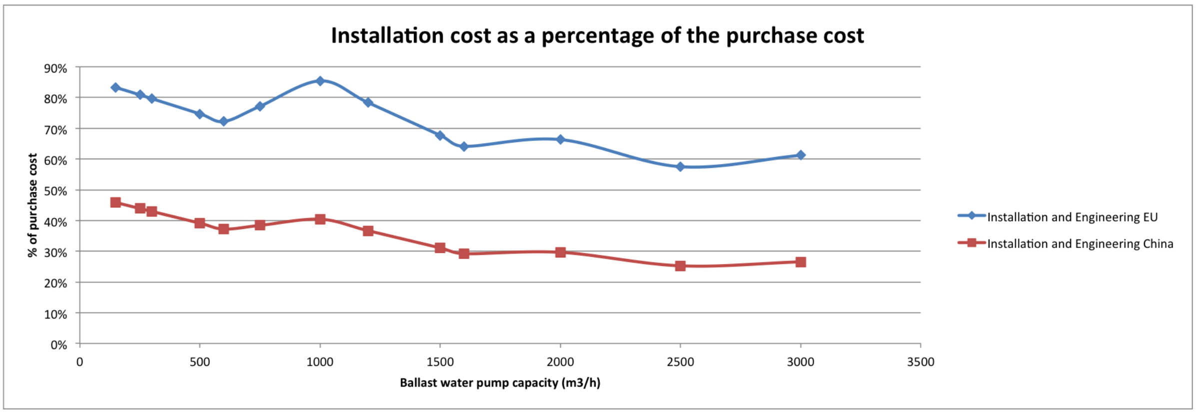


Figure 5.1: Engineering and installation cost as a percentage of the purchase cost for UV and EC systems

For the inert gas system different installation costs are used. The engineering cost is assumed to be the same. Installation prices in Chinese yards are known and European prices are again calculated with a factor of 2.5 [**?**]. These numbers are again shown as a percentage of the purchase cost. As can be seen from figure **??** the engineering and installation cost for an inert gas system are much higher. This is caused by the fact that units need to be installed in every ballast tank. The one point that shows installation cost of just over 100% is assumed to be a special case where the installation costs turned out higher than expected. As the difference is not too big between the rest of the data points, it is kept for the analysis.
FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS
These prices are used in the tool, which will be explained in chapter 7, to get an estimation of the total cost of the BWT system. The prices of the UV and EC ballast water treatment systems do not differ in price as discussed in section 5.1. The price can thus be calculated by the ballast water pump capacity. The owner then has to choose according to the vessel-specific needs, as discussed in chapter 3.

Figure **??** and **??** show the total cost of purchase price, engineering and installation in Europe and China respectively.
TWO FIGURES NOT SHOWN DUE TO CONFIDENTIALITY REASONS

5.3. Operational expenses for the ballast water treatment system

Besides the purchase and installation cost of the ballast water treatment system, the operational expenses should also be taken into account. The operational expenses of an UV system with medium pressure lamps will include the following:

- Parts and consumables
- Fuel consumption

The parts and consumables consist of:

- UV Lamps
- CIP liquids
- CIP pump kits
- CIP spares kits
- Filter seal kits
- Lamp power supplies
- UV sensors

Both the fuel consumption and the parts and consumables are dependent on the ballast profile of the vessel. It is assumed for each vessel that the ballasting time per year would come down to 1,200 hours with maximum power. This assumption is made with the insight of several ballast water treatment manufacturers that claim that this is a typical ballasting time for a vessel with a lot of ballasting and de-ballasting [?], [?], [?]. It is based on approximately 50 ballasting cycles. This includes ballasting and de-ballasting. With 12 hours of ballasting and de-ballasting this comes down to 1,200 hours of treatment. Equation 5.3 shows the calculation.

$$Yearly\,ballasting\,profile = 50\,(cycles) * 2\,(ballasting + de-ballasting) * 12\,(ballasting\,hours) \tag{5.1}$$

This assumption is based on an interview with both a manufacturer and a ship owners who state that this was a typical high ballasting profile [?] [?].

For the fuel consumption and its prices a few assumptions are made, these are shown in table 5.2. All vessels that are analysed are assumed to be sailing on IFO 180. The pricing is set at the highest Rotterdam price in April 2017.

Fuel price	IFO 180	350 $/tonne [?]
Fuel consumption	SFOC	210 g/kWh [?]
Energy cost		0.0735 $ / kWh

Table 5.2: Assumptions made for the fuel consumption of the ballast water treatment systems

5.3.1. Opex UV systems

The UV ballast water treatment system with a lot of consumables is assumed to be a costly system when looking at operational expenses. Two ballast water treatment systems with a pump capacity of 170 m3/h and 1,000 m3/h have been examined. The following assumptions and calculations are used to come up with the operational costs for each system.

Fuel cost	350	$ / tonne
SFOC	210	g/kWh
Power consumption	100	kW
Yearly operation	1,200	hours
Power required	120,000	kWh
Yearly consumption price	$ 8.820	

Table 5.3: Power consumption for a UV 1.000 m3/h system with 1.200 yearly operating hours [**?**]

Consumable	Nr. consumables in 10 years
UV lamp kit	64
CIP liquid	10
CIP pump kit	5
CIP spares kit	5
Filter seal kit	5
Lamp power supply (LPS)	16
UV sensor	5
Total consumables in 10 years	$ 59,000
Total consumables per year	$ 5,900

Table 5.4: Parts and consumables for an UV 1,000 m3/h system with 1,200 yearly operating hours (600,000 m3) [**?**]

The same is done for a 170 m3/h system with 1.200 yearly operating hours.

Fuel cost	350	$ / tonne
SFOC	210	g/kWh
Power consumption	17	kW
Yearly operation	1,200	hours
Power required	20,400	kWh
Yearly consumption price	$ 2,999	

Table 5.5: Power consumption for a UV 170 m3/h system with 1,200 yearly operating hours (204,000 m3) [**?**]

Consumable	Nr. consumables in 10 years
UV lamp kit	24
CIP liquid	10
CIP pump kit	5
CIP spares kit	5
Filter seal kit	5
Lamp power supply (LPS)	3
UV sensor	5
Total consumables in 10 years	$ 35,500
Total consumables per year	$ 3,550

Table 5.6: Parts and consumables for an UV 170 m3/h system with 1,200 yearly operating hours [**?**]

As discussed before, this is considered one of the most costly ballast water treatment systems when looking only at operational expenses. As these costs are relatively very small compared to the operational cost of the vessel, it is assumed that this operational expense is equal for the inert gas ballast water treatment systems. Because the tool the cash flow models are based on yearly time charter rates, the power consumption is for the account of the charterer. This leaves only the consumables as an extra cost for the ship owner. The two known yearly consumable costs are linearised so that for all UV and inert gas ballast water treatment system, the consumable costs can be calculated. This is shown in figure 5.2.

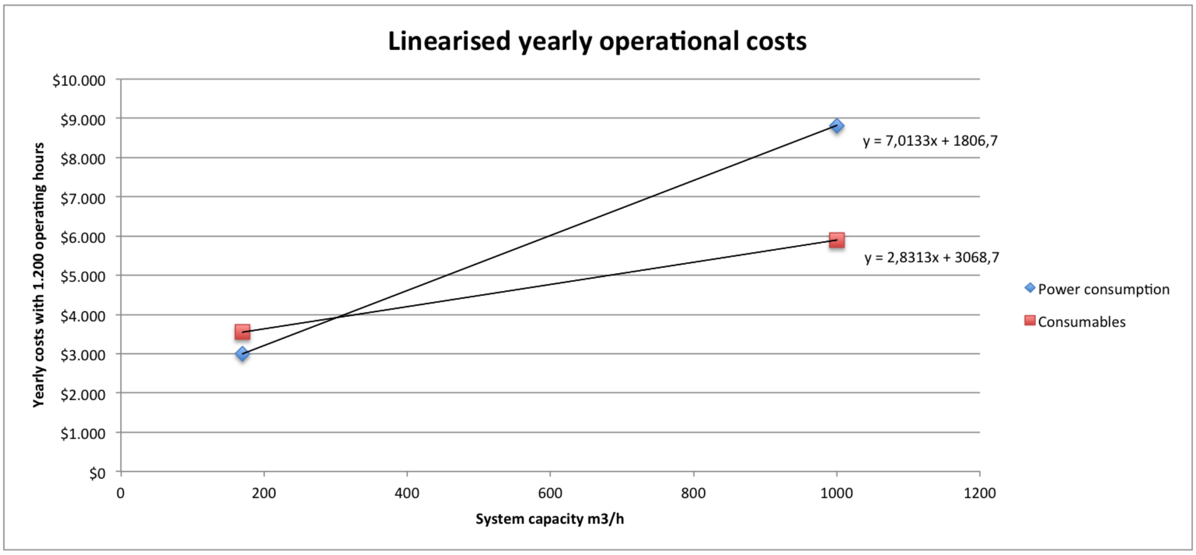


Figure 5.2: Operational expenses for the UV and Inert Gas ballast water treatment systems

By linearising the consumables for the two ballast water treatment capacities, the following formula is derived:

$$Yearly\, price\, consumables = 2.83\, X + 3068.7 \tag{5.2}$$

$$X = Ballast\, water\, treatment\, capacity \tag{5.3}$$

The consumables for a UV system can now be calculated as a function of the ballast water treatment capacity, with the assumption of a 1,200 hour ballasting profile.

5.3.2. Opex EC systems

An analysis has also been executed for the electrolysis systems. Because the electrolysis system operates at the intake of ballast water, only half of the operational time is required, as discussed in chapter 4. This means that for the electrolysis systems a 600 hour ballast profile is assumed instead of 1,200. The following assumptions and calculations are used to come up with the operational costs for each system.

Fuel cost	350	$ / tonne
SFOC	210	g/kWh
Power consumption	92	kW
Yearly operation	600	hours
Power required	55,200	kWh
Yearly consumption price	$ 4,057	

Table 5.7: Power consumption for a UV 1,000 m3/h system with 600 yearly operating hours [?]

Consumable	Nr. consumables in 10 years
CLX Reagent	1
Distilled water	6
Neutralizing agent (Na2S203)	150
Citric acid	81
Total consumables in 10 years	$ 15,000
Total consumables per year	$ 1,500

Table 5.8: Parts and consumables for an EC 1,000 m3/h system with 600 yearly operating hours (600,000 m3) [?]

The same is done for a 600 m3/h system with 600 yearly operating hours.

Fuel cost	350	$ / tonne
SFOC	210	g/kWh
Power consumption	55	kW
Yearly operation	600	hours
Power required	33,000	kWh
Yearly consumption price	$ 2,425	

Table 5.9: Power consumption for a UV 600 m3/h system with 600 yearly operating hours [?]

Consumable	Nr. consumables in 10 years
CLX Reagent	1
Distilled water	6
Neutralizing agent (Na2S203)	90
Citric acid	48
Total consumables in 10 years	$ 12,500
Total consumables per year	$ 1,250

Table 5.10: Parts and consumables for an UV 600 m3/h system with 600 yearly operating hours (120,000 m3) [?]

By comparing the results from an UV system and an EC system, it can be seen that both the costs of consumables and fuel consumption are higher for an UV system. Because in the tool the cash flow models are based on yearly time charter rates, the power consumption is for the account of the charterer. The power consumption of the UV systems are twice as expensive compared to the EC systems. This could be an incentive to the charterer to charter a vessel with a EC system instead of an UV system. On the other hand, the daily power consumption for a 1,000 m3/h system would come down to a maximum of $ 24.- and the same EC system $12.-. As these costs are so low, it is assumed that this will not influence the charterer. This leaves only the consumables as an extra cost for the ship owner. The two known yearly consumable costs are linearised so that for all EC ballast water treatment system, the consumable costs can be calculated. This is shown in figure 5.3.

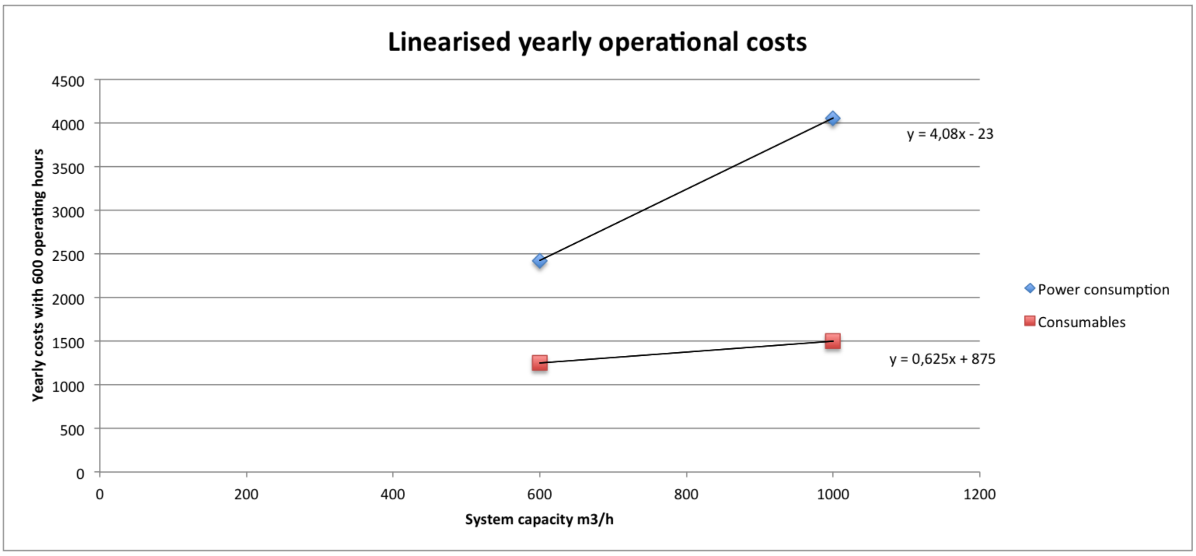


Figure 5.3: Operational expenses for the EC ballast water treatment systems [?]

By linearising the consumables for the two ballast water treatment capacities, the following formula is derived:

$$Yearly\, price\, consumables = 0.625\, X + 875 \tag{5.4}$$

$$X = Ballast\, water\, treatment\, capacity \tag{5.5}$$

Now the consumables for a UV system can be calculated as a function of the ballast water treatment capacity, with the assumption of a 600 hour ballasting profile.

6
Implementation strategies

Now that the going into-force date of the IMO BWM convention and the USCG implementation date are known, ship owners can prepare for compliance. The IMO and the USCG have a different compliance schedule. Figure 6.1 shows an overview of the compliance schedule for both the IMO and the USCG. This chapter will discuss the 23 possible strategies that can be followed to comply with the IMO and the USCG. For the use of the tool, assumptions are made, bringing the number of feasible strategies down to 6. These will be discussed at the end of this chapter.

Figure 6.1: Compliance schedule for IMO and USCG approval.

Type	Ballast water capacity	Date of keel lay	Compliance date	
New build vessel	All	On or after 1-12-2013	On Delivery	**USCG Approval**
Existing vessel	<1500 m3	Before 1-12-13	First scheduled drydocking after 1-1-2016	
Existing vessel	1500-5000 m3	Before 1-12-13	First scheduled drydocking after 1-1-2014	
Existing vessel	>5000 m3	Before 1-12-13	First scheduled drydocking after 1-1-2016	
New build	All	On or after 8-9-2017	On Delivery	**IMO Approval**
Existing vessel	All	All	First scheduled IOPP renewal after 8-9-2017	

Depending on the sailing routes, the vessel has to comply with the IMO and/or USCG regulation. Figure 6.2 shows the countries that signed the IMO convention in red and the area which is under inspection of the USCG in blue.

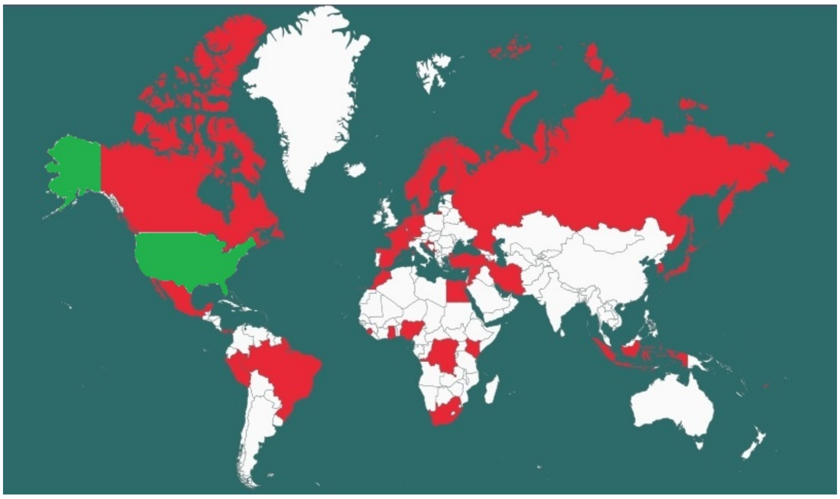


Figure 6.2: World map showing countries that signed the IMO convention on 21-2-17 in red and USCG area in blue.

The amount and spread of countries that signed the BWM convention implies that all sea going merchant vessels will have to comply with the upcoming regulation.

6.1. Extending compliance schedule

For both the IMO and the USCG there is a way to extend the compliance schedule. This section will explain the possibilities to postpone the compliance schedule.

6.1.1. IMO extending compliance date

The IMO, the compliance date is dependent on the IOPP renewal. The IOPP which stands for, International Oil Pollution Prevention certificate, has to be renewed every five years. As of 2003 a harmonised system of surveys and certifications was adopted by the IMO [?]. This was done to reduce the problems caused by survey dates with different intervals. The IOPP renewal is harmonised in the renewal survey, which includes dry-docking as shown in figure C.1 in Appendix C.

For the IMO, the compliance schedule can be postponed by de-harmonization of the IOPP. This means that the IOPP no longer has to be executed during dry-docking. Some flag states, including The Netherlands, have allowed de-harmonisation of the renewal survey. In the case of de-harmonisation under the Dutch flag, the anniversary date has to remain. As shown in figure 6.3 this IOPP renewal can be executed between three months prior and three months after the initial anniversary date. The IOPP renewal can give the ship owner a maximum of five years extension on the initial implementation date. This is the case when the scheduled dry-dock was planned just after the going into-force date. The vessel can sail for another 5 years without a BWTS when performing an early IOPP renewal just before the going into-force date.

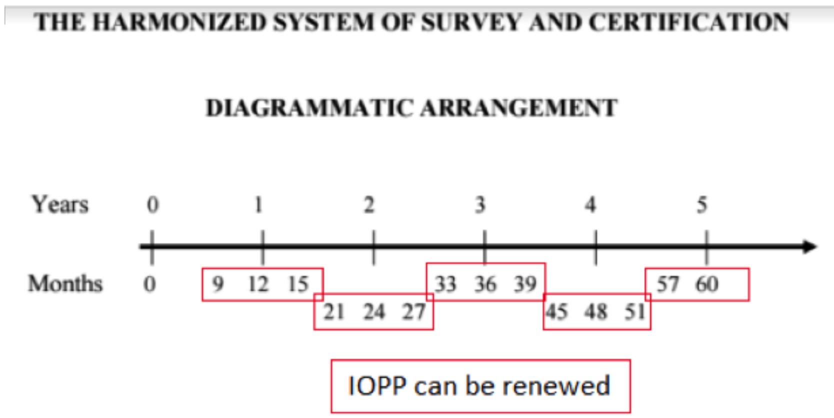


Figure 6.3: IOPP renewal under Dutch flag.

6.1.2. USCG extending compliance date

The USCG set regulations which should be implemented as of the end of 2013. Until December 2016 [?] no available ballast water treatment method type was approved by the USCG. This is why the USCG introduced the Alternate Management System (AMS) program. Ballast water treatment systems can receive AMS approval. Foreign administration approved ballast water management systems could receive this. Almost all IMO approved systems received AMS approval. *"A vessel may continue to manage ballast water with an AMS for up to 5 years after the date it is required to comply with the BWDS implementation schedule in CFR 151.1512(b) or 151.2035(b)."* [?]. This extension of the compliance date of the USCG comes with a high price because a ballast water treatment system has to be installed, yet it is not fully approved by the USCG. This extension can be seen more as an extension for the manufacturer to receive USCG approval within five years and be able to serve their customers in between. Now that the USCG has approved three BWT systems as from May 2017, the AMS approvals are getting less attractive. USCG is getting stricter on the initial regulation now that some BWT system are approved.

6.2. Possible scenarios

All of the possible strategies concerning the installation date of a ballast water treatment system will be discussed in this chapter. The strategies eventually all end in different scenarios, which are shown in the overview in table 6.1.

Scenario	Description
Install a BWT system	This can either be IMO and/or USCG approved system
No BWT system is required	The vessel reaches the end of its lifetime of 20 years, before a BWT system is required
Sell or Scrap	The vessel is to be sold or scrapped before the end of its lifetime
Use alternative BWT method	An alternative BWT method can be used without installing a system
Install No BWT	*Hypothetical scenario to calculate the impact of the BWM convention*

Table 6.1: Different scenarios with short description

The four scenarios can be accomplished by 23 different paths. These paths are the different strategies which guide to one of these scenarios except for the hypothetical scenario of not installing a BWT system, which is not feasible. All 23 different strategies are schematically shown in figure 6.4. Because this research only focusses on existing vessels, which come with the most possibilities in strategies, new-build vessels are not shown. Going from top to bottom in time, OR signs can be found. This means that at this point the ship owner has to make a decision. Some decisions imply that the vessel does not comply with the USCG anymore. This is shown by a US flag with forbidden sign. In some cases, the vessel may be in compliance with the USCG in the end. This is then shown with a US flag. All events are coloured, this shows whether the decision chooses to comply (Green), no decision on compliance made (Yellow) or it will mean the company will be out of business (Red) with this specific vessel. All 23 different strategies will now be discussed.

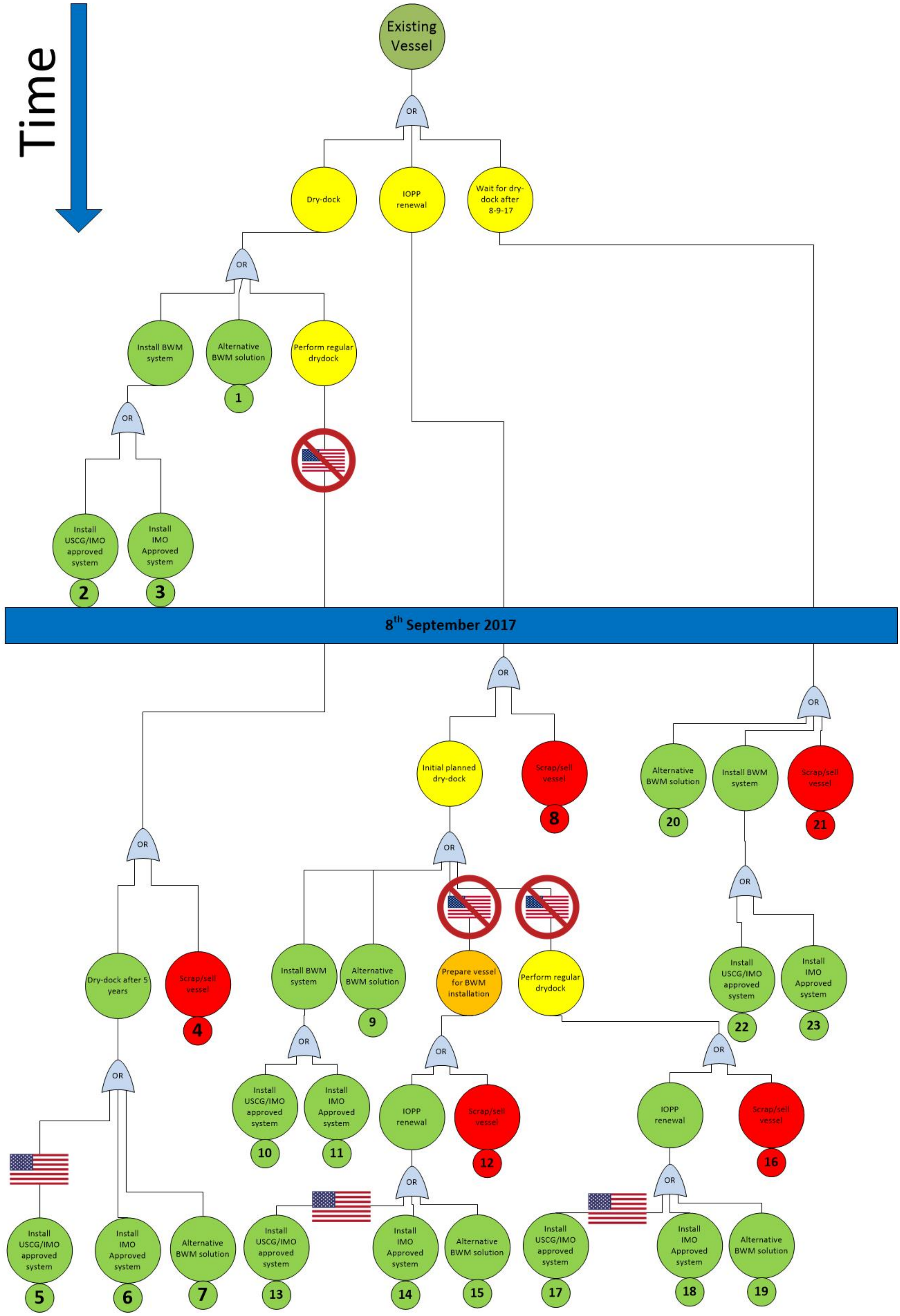


Figure 6.4: Strategy flow chart.

6.3. Strategy descriptions

The differently numbered strategies shown in the overview of figure 6.5 will be discussed in this section. The strategies differ in: postponement of implementation, investment needed for the system, investment spread, extra investment for extension of compliance, USCG compliance, IMO compliance and whether the vessel will be in business at the end. To give a good and clear insight of the influence on these parameters depending on the strategy, an overview is made with clear symbols. The overview with the legend of the symbols is shown in figure 6.5.

Figure 6.5: Symbols used in strategies.

6.3.1. Strategies (1-7), dry-dock before 8th of September 2017

Strategy 1 IMO

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Make use of an alternative BWM solution
Possible gain:	The vessel will comply without the investment of a ballast water treatment system. As a first mover where demand for BWT systems is still low, prices can be low.
Possible loss:	The alternative solution may not be available in all ports. This can make the ballasting difficult to manage.
Compliance:	Depending on the alternative solution, the vessel will be in compliance with IMO and/or USCG.

Strategy 2

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Install a BWM system
Step 3:	Install an USCG/IMO approved system
Possible gain:	Demand is still low, so prices of both systems and yards are low.
Possible loss:	After 5 years there is a lot more experience with technologies and installation. Prices could be lower and the technology has improved.
Compliance:	The vessel will be in compliance with the IMO and USCG.

Strategy 3

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Install a BWM system
Step 3:	Install an IMO approved system
Possible gain:	Demand is still low, so prices of both systems and yards are low. From this moment on you have 5 years AMS approval which gives the manufacturer time to comply with the USCG.
Possible loss:	When the system does not get USCG type approved, the ship owner can only sail for 5 years in US waters from the moment of installation.
Compliance:	The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There still is a possibility of USCG type approval of the system within this period.

Strategy 4

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Perform a regular dry-dock
Step 3:	Before next dry-dock (5 years), Scrap the vessel
Possible gain:	The ship is able to sail for 5 years without the investment of a BWM system.
Possible loss:	The vessel did not make sufficient money over the last 5 years and scrap prices are lower than 5 years ago
Compliance:	The vessel will be scrapped, so no compliance is needed. The vessel will be out of business.

Strategy 5

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Perform a regular dry-dock
Step 3:	Dry-dock 5 years later
Step 4:	Install an USCG/IMO approved system
Possible gain:	More systems are USCG type approved and there is a lot more experience with technologies and installation. Prices are low and technologies are better.
Possible loss:	Demand is high and supply is low. Prices are high and waiting times makes it even more expensive.
Compliance:	The vessel will be in compliance with the IMO and USCG.

Strategy 6

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Perform a regular dry-dock
Step 3:	Dry-dock 5 years later
Step 4:	Install an IMO approved system
Possible gain:	More systems have been IMO type approved and there is a lot more experience with technologies and installation. Prices are low and technologies are better.
Possible loss:	Demand is high and supply is low. Prices are high and waiting time makes it even more expensive. Not able to sail in US waters.
Compliance:	The vessel will be in compliance with the IMO. There is a small possibility that the system will get USCG type approval but the vessel cannot use the system until this point in US waters.

Strategy 7

Step 1:	The vessel performs a dry-dock before 8-9-17
Step 2:	Perform a regular dry-dock
Step 3:	Dry-dock 5 years later
Step 4:	Make use of an alternative BWM solution
Possible gain:	More systems have been IMO/USCG type approved and there is a lot more experience with technologies and installation. This will also count for the alternative BWM solutions. A better cost weighted decision could be made with more options to choose from.
Possible loss:	Demand is high and supply is low. Prices are high and waiting times makes it even more expensive. This can drive up the prices of alternative solutions as well.
Compliance:	Depending on the alternative solution, the vessel will be in compliance with IMO and/or USCG.

6.3.2. Strategies (8-19), Perform IOPP renewal before 8th September 2017

Strategy 8

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Before initial dry-dock, scrap vessel

Possible gain: With the IOPP renewal the owner has the option to sail for 5 more years without the installation costs. When the costs of putting the vessel in dry-dock is too high the owner has the choice to scrap the vessel.

Possible loss: The vessel did not make sufficient money over the last few years. The cost of an IOPP renewal was a waste in this case.

Compliance: The vessel will be scrapped, so no compliance is needed. The vessel will be out of business.

Strategy 9

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Make use of an alternative BWM solution

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation. This will also count for the alternative BWM solutions. A better cost weighted decision could be made with more options to choose from.

Possible loss: The extra costs of an early IOPP renewal and eventually not installing a BWM system at all is a costly move but gives the owner the choice whether to install.

Compliance: Depending on the alternative solution, the vessel will be in compliance with the IMO and/or USCG.

Strategy 10

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Install a BWM system
Step 4: Install an USCG/IMO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation, prices can be low. It would be a strategic move to install now when you expect that the demand/price will be higher at the next IOPP renewal.

Possible loss: The extra costs of an early IOPP renewal and eventually executing the BWM system installation is a costly move but gives the owner the choice whether to install.

Compliance: The vessel will be in compliance with the IMO and USCG.

Strategy 11

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Install a BWM system
Step 4: Install an IMO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation, prices can be low. It would be a strategic move to install now when you expect that the demand/price will be higher at the next IOPP renewal.

Possible loss: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation, prices can be low. It would be a strategic move to install now when you expect that the demand/price will be higher at the next IOPP renewal. A system which is only approved by the IMO could be cheaper. When this is the first dry-dock after 2014 or 2016, dependent on the ballast capacity, you would still have a 5 year AMS certificate.

Compliance: The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There is still a possibility of type approval of the system within this period.

Strategy 12

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Prepare the vessel for BWM system installation
Step 4: Before IOPP renewal (5 years) scrap the vessel

Possible gain: With the IOPP renewal the owner has 5 more years to sail without the installation costs. At this time the owner has 2 possible dates whether to install a system. This gives the owner the time to see whether the market grows.

Possible loss: The vessel did not make sufficient money over the last 5 years. The choice of an IOPP renewal and a dry-dock and the preparation for a BWM system is be a costly decision.

Compliance: The vessel will be scrapped, so no compliance is needed. The vessel will be out of business.

Strategy 13

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Prepare the vessel for BWM system installation
Step 4: Perform an IOPP renewal
Step 5: Install an USCG/IMO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low. The fact that the owner prepared the vessel in the previous dry-dock makes it easy to install the system without going in to dry-dock. The owner benefits from the fact that the total investment cost is spread out over the previous dry-dock and the IOPP renewal.

Possible loss: The total cost of preparation and installation on a different moment in time will be more expensive than doing it all at once. Furthermore the systems could be more expensive because of a higher demand.

Compliance: The vessel will be in compliance with the IMO and USCG.

Strategy 14

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Prepare the vessel for BWM system installation
Step 4: Perform an IOPP renewal
Step 5: Install an MO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low. The fact that the owner prepared the vessel in the previous dry-dock makes it easy to install the system without going in to dry-dock. The owner benefits from the fact that the total investment costs is spread out over the previous dry-dock and the IOPP renewal.

Possible loss: The total cost of preparation and installation on a different moment in time will be more expensive than doing it all at once. Furthermore the systems could be more expensive because of a higher demand. The IMO approved system will only be AMS approved for 5 years from the initial planned dry-dock.

Compliance: The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There still is a possibility of type approval of the system within this period.

Strategy 15

Step 1:	The vessel renews IOPP before 8-9-17
Step 2:	Perform initial planned dry-dock
Step 3:	Prepare the vessel for BWM system installation
Step 4:	Perform an IOPP renewal
Step 5:	Make use of an alternative BWM solution

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low. This will also count for alternative BWM solutions. A better cost weighted decision could be made with more options to choose from.

Possible loss: The preparation for the installation of a BWM system is obsolete. This costed more than eventually necessary.

Compliance: Depending on the alternative solution, the vessel will be in compliance with the IMO and/or USCG.

Strategy 16

Step 1:	The vessel renews IOPP before 8-9-17
Step 2:	Perform initial planned dry-dock
Step 3:	Perform a regular dry-dock
Step 4:	Before IOPP renewal (5 years) scrap the vessel

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low. This will also count for alternative BWM solutions. A better cost weighted decision could be made with more options to choose from. When it seems not profitable to install or use alternative methods, the vessel can be scrapped.

Possible loss: Demand is high and supply is low. Prices are high and waiting times makes it even more expensive. This can drive up the prices of alternative solutions as well, forcing the vessel to be scrapped.

Compliance: The vessel will be scrapped, so no compliance is needed. The vessel will be out of business.

Strategy 17

Step 1:	The vessel renews IOPP before 8-9-17
Step 2:	Perform initial planned dry-dock
Step 3:	Perform a regular dry-dock
Step 4:	Install a BWM system
Step 5:	Install an USCG/IMO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low.

Possible loss: The fact that there was no preparation during dry-dock, this will increase the cost and time needed during an IOPP renewal.

Compliance: The vessel will be in compliance with the IMO and USCG.

Strategy 18

Step 1:	The vessel renews IOPP before 8-9-17
Step 2:	Perform initial planned dry-dock
Step 3:	Perform a regular dry-dock
Step 4:	Install a BWM system
Step 5:	Install an IMO approved system

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low.

Possible loss: The fact that there was no preparation during dry-dock, this will increase the cost and time needed during an IOPP renewal. The IMO approved system will only be AMS approved for a maximum of 5 years from the initial planned dry-dock.

Compliance: The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There still is a possibility of type approval of the system within this period.

Strategy 19

Step 1: The vessel renews IOPP before 8-9-17
Step 2: Perform initial planned dry-dock
Step 3: Perform a regular dry-dock
Step 4: Perform an IOPP renewal
Step 5: Make use of an alternative BWM solution

Possible gain: With the IOPP renewal the vessel has 5 years to install a system. When the industry already has enough experience with technologies and installation prices are low. This will also count for alternative BWM solutions. A better cost weighted decision could be made with more options to choose from.

Possible loss: Demand is high and supply is low. Prices are high and waiting times makes it even more expensive. This can drive up the prices of alternative solutions as well.

Compliance: The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There still is a possibility of type approval of the system within this period.

6.3.3. Strategies (20-23), wait for initial dry-dock after the 8th of September 2017

Strategy 20

Step 1: Wait for initial dry-dock
Step 2: Make use of an alternative BWM solution

Possible gain: The owner can sail the vessel for some more years without having to make any more investments. Further developments in alternative BWM solutions can come up.

Possible loss: The alternative solution may still not be available in all ports. This can make the ballasting difficult to manage.

Compliance: Depending on the alternative solution, the vessel will be in compliance with the IMO and/or USCG.

Strategy 21

Step 1: Wait for initial dry-dock
Step 2: Before initial dry-dock scrap the vessel

Possible gain: The owner can sail the vessel for some more years without having to make any more investments.

Possible loss: Scrap prices can be low because of a large old fleet which is going to be scrapped for the same reason.

Compliance: The vessel will be scrapped, so no compliance is needed. The vessel will be out of business.

Strategy 22

Step 1: Wait for initial dry-dock
Step 2: Install a BWM system
Step 3: Install an USCG/IMO approved system

Possible gain: Depending on when the dry-dock was planned, the industry has some time to improve the technology and install in a more efficient way. Prices could be low when considering all owners who extended the installation with 5 years.

Possible loss: Prices can still be high as not enough experience is gained regarding technology and installation.

Compliance: The vessel will be in compliance with the IMO and USCG.

Strategy 23

Step 1: Wait for initial dry-dock
Step 2: Install a BWM system
Step 3: Install an IMO approved system

Possible gain: Depending on when the dry-dock was planned, the industry has some time to improve the technology and install in a more efficient way. Prices could be low when considering all owners who extended the installation with 5 years. Demand for only IMO approved systems are probably low so prices are too.

Possible loss: Demand is high and supply is low. Prices are high and waiting times makes it even more expensive.

Compliance: The vessel will be in compliance with the IMO. When the installed system is AMS certified, the vessel could sail for a maximum of five years, depending on the previous dry-dock date and ballast capacity. There still is a possibility of type approval of the system within this period.

6.4. Strategy analysis

Some strategies will be more common and logical than others but, because of an ever changing market, all strategies should be considered. This section will show insight in the expected strategies to be used. All the discussed strategies are mainly influenced by the ballast water treatment technology, its improvements and pricing. Next to the ballast water treatment system itself, the scrap/sell price is a determining factor in the described strategies. The cost analysis which is done in chapter 5, shows the costs for a ballast water treatment system as of February 2017. Fluctuations of the pricing of ballast water treatment systems would be soley based on speculations. This is why it is assumed that the pricing of the ballast water treatment systems will remain stable. The cost analysis does not show any differences between the IMO approved and USCG approved system. USCG approval is something that is excpected to be received all the manufactures discussed in in chapter 4. No increase in price is expected, as the USCG approved systems are equally priced. The scrap/sell price of the vessel is something marine consultants like MSI [**?**] and Clarksons [**?**] can predict. This is why this is a variable that is taken into account when predicting the ideal and vessel-specific strategy.

Calculating the purchase and installation cost of a BWT system for each vessel is a fairly simple. To put things in perspective, the impact on the business has to be reviewed. This means that the market position of each vessel has to be determined. To gain insight into the impact of the system for each vessel, it is important to see what the impact is compared to the business now, without a ballast water treatment system. This can be realised by creating cash flow models to gain insight in the cash flows of the vessel. These cash flow models can then show the impact of the ballast water treatment system on the business.

To realize such comparison, a tool which is described in chapter 7, is created. The tool will look at the ideal vessel-specific strategy with the following main parameters:

- Vessel value (variable cost, forecast)
- T/C rates (variable costs, forecast)
- Opex (variable costs, forecast)
- Ballast water treatment cost (fixed costs dependent on strategy)

With these assumptions, some strategies that were discussed in this chapter will become a ideal strategy. Also, the strategies where an alternative ballast water management solution is used can not be calculated this way. In table 6.2 each strategy discussed in this chapter will be assessed to be feasible or not, based on the parameters used in the tool.

Strategy	**Feasible?**	**Description**
1	No	Alternative solution not considered
2	Yes	Same as strategy 22 except from timing, dependent on anniversary date
3	No	Not USCG approved
4	Yes	Feasible when regular dry-dock is planned before 8th of September
5	Yes	Feasible when regular dry-dock is planned before 8th of September
6	No	Not USCG approved
7	No	Alternative solution not considered
8	No	Extra cost of IOPP renewal but same outcome as strategy 21
9	No	Alternative solution not considered
10	No	Extra cost of IOPP renewal but same outcome as strategy 2 and 22
11	No	Not USCG approved
12	No	Extra cost for preparing for BWT but same outcome as strategy 16
13	No	Feasible when pricing of BWT cost distribution is more convenient than strategy 17 which is not the case with current assumptions
14	No	Not USCG approved
15	No	Alternative solution not considered
16	Yes	Feasible when IOPP renewal makes more possible income and higher sell/scrap vessel value
17	Yes	Feasible when the postponement is more convenient than the distribution of the investment
18	No	Not USCG approved
19	No	Alternative solution not considered
20	No	Alternative solution not considered
21	Yes	Feasible when IOPP renewal does not make more possible income and higher sell/scrap vessel value
22	Yes	Same as strategy 2 except from timing, dependent on anniversary date
23	No	Not USCG approved

Table 6.2: Most feasible strategies based on the parameters used in the tool.

Strategy 13 would seem like a feasible solution when the owner has a convenience compared to strategy 17 when changing the investment timing.
Strategy 13 would perform IOPP renewal, prepare BWT in dry-dock and finish BWT installation before the next IOPP renewal.

Strategy 17 performs IOPP renewal, regular dry-dock and installs the BWT before the next IOPP renewal. The assumptions that were made are shown in figure 6.6.

The fact that strategy 17 is feasible and 13 is not means that the assumptions that were made determined that strategy 17 is a better solution based on the highest IRR. This will now be briefly explained.

IOPP additional costs		€	6,500
Preparation cost %			80%
Finalizing cost %			30%
Extra cost to install at IOPP renewal %			10%
low price limit Prep costs (80% of installation cost)		$	91,940
low price limit Installation cost (100% system + 30% installation cost)		$	467,115
Total low price limit		$	559,055
high price limit Prep costs (80% of installation cost)		$	341,312
high price limit Installation cost (100% system + 30% installation cost)		$	869,992
Total high price limit		$	1,211,304
low price limit	Installation at IOPP without prep	$	559,055
high price limit	Installation at IOPP without prep	$	1,211,304

Figure 6.6: Overview of the assumptions made for strategy 13 and 17

Figure 6.6 shows an example of the price overview for both strategy 13 and 17 regarding the ballast water treatment installation. For both strategies the IOPP costs are the same. Also both strategies assume that the total installation cost goes up by 10% so the total cost of both strategies is the same. The difference is caused by the fact that the costs are split with strategy 13. With the calculation of the IRR, future expenditures are less important compared to expenditures now. This implies that the preparation part of the of strategy 13 has a negative impact on the IRR compared to strategy 17. This is the logical explanation for the fact that strategy 13 did not turn out to be a strategy with the highest IRR when performing a fleet analysis.

6.5. Selection of feasible strategies

The analysis implies that with the use of the tool only a few of the 23 strategies would possibly be feasible. The tool will thus only consider the following ballast water treatment implementation strategies:

- Strategy 2 (Installation of a BWT system during first next dry-dock (first planned dry-dock after 8th of September 2017))
- Strategy 4 (Sell/scrap vessel before second dry-dock (first planned dry-dock before 8th of September 2017))
- Strategy 5 (Installation of a BWT system during second dry-dock (first planned dry-dock before 8th of September 2017))
- Strategy 16 (IOPP renewal, perform regular dry-dock and sell/scrap vessel before IOPP renewal)
- Strategy 17 (IOPP renewal, perform regular dry-dock and install BWT before IOPP renewal)
- Strategy 21 (Sell/scrap vessel before first dry-dock (first planned dry-dock after 8th of September 2017))

This is based on the assumption that the pricing of a ballast water treatment system does not change over time. Furthermore the pricing of an IMO and an USCG approved systems is equal. More assumptions will be discussed in chapter 7 which will give a detailed explanation on the tool that is created.
All strategies can be placed within the scenarios which are discussed in chapter 6. An overview of the feasible scenarios with the corresponding strategies can be found in table 6.3.

Scenario	Strategies
Install a BWT system	2, 5, 17
No BWT system is needed	4, 16, 21
Sell or Scrap	4, 16, 21
Use alternative BWT method	No strategies, not considered for this research
Install No BWT	*Hypothetical*

Table 6.3: Different scenarios with short description

Table 6.3 shows that the same strategies can have a different scenario. Strategies 4, 16 and 21 all end with selling or scrapping the vessel. When the vessel is scrapped due to the fact that the vessel aged 20, it is considered a *No BWT system is needed* scenario. When the vessel is not at the end of its lifetime but is sold or scrapped anyhow, it is considered a *Sell or scrap* scenario.

7

Tool description

Now that all different treatment methods and possible strategies are being discussed, a generic tool is created to come up with the best strategy for a specific vessel. The tool will be able to create cash flow models and calculate the internal rate of return (IRR). This can be calculated for all different strategies and three different market cases: pessimistic, base case and optimistic. The tool is created in a way that it can easily be adjusted and used for multiple purposes. This chapter will elucidate how the tool works and illustrate the assumptions that were made.

7.1. Main goal of the tool

The main goal of the tool is to give a vessel-specific strategy advise, based on the highest possible IRR for every scenario. It is assumed that the initial investment is today's vessel value. The IRR is then calculated in different points in time according to the strategy which is followed. As a comparison, this is also done for the hypothetical scenario where no ballast water treatment system is installed. The difference between these IRR's represents the impact of the ballast water treatment system on the IRR of the vessel. In the interaction between the bank and the shipowners this tool helps to get a quick insight in the vessels' financial performance and what strategy to use. NIBC can use this tool to analyse the strategy that a ship owner is proposing. NIBC can subsequently advise ship owners to follow the optimal strategy. Furthermore the tool can be used to appoint vessels with a weak forecast in financial performance.

7.2. Internal rate of return IRR

The internal rate of return is a widely used metric to measure the return on each dollar invested. The IRR is the discount rate whereby the net present value of all cash flows related to an investment equals zero. A more detailed description on how to calculate the net present value is discussed in section 7.6. The IRR makes it possible to compare different investments with each other [**?**]. When the IRR is greater than the expected return on capital, the project should be accepted. When the IRR is less than the expected return on capital, the project should be rejected. In this tool the strategy with the highest IRR is selected. This means this strategy will give the ship owner the highest possible return on investment. By showing the difference between the IRR's, the owner has a clear overview of the possible returns. Furthermore it shows the impact on return, caused by the extra investment needed to install a ballast water treatment system.

7.3. The basic description of the tool

The tool is able to create cash flow models based on historic and forecasted rates from MSI [**?**]. This is done for every strategy, resulting in six cash flow models. Each cash flow model contains three cases: Pessimistic, Base case and Optimistic. The cases differ in T/C rates in which the base case refers to the MSI forecasted rate. The optimistic and pessimistic rates are calculated by adding and subtracting 5% from the forecasted rate (base case). For the scenario where a ballast water treatment system is installed, all cases are also calculated for a low-price and high-price system, giving a range of prices for which the BWT system can be bought. Every strategy is checked whether it is feasible to follow. The IRR can then be calculated for every strategy and case. The strategy with the highest IRR from every scenario is then selected. The scenario and strategy with the highest IRR is then selected and proposed as the ideal strategy to follow. The IRR can then be compared with the hypothetical IRR where no regulation applies and no BWT system is installed, giving the impact of the regulation. A brief overview of the procedure is shown in table 7.1.

Scenario	**Strategy**	**Calculation**	**Output**
Install a BWT system	2 5 17	Highest IRR	
No BWT system is needed	4 16 21	Highest IRR	Scenario and strategy with highest IRR
Sell or Scrap	4 16 21	Highest IRR	
Install no BWT system		IRR	Hypothetical IRR to calculate the impact

Table 7.1: Description on how the tool comes up with the ideal strategy and impact on IRR.

Because a cash flow models is created for every strategy, a lot of data can be derived from it. All the output that is used for the analysis is will be discussed in this chapter.

7.4. input for the NIBC tool

The input of the tool is very important. Some input data has to be updated quarterly while other input, like the NIBC database has to be updated when the portfolio changes. This section will show all of the used input data. Section 7.6 discusses how the input is used to create the output which is shown in section 7.9.

7.4.1. NIBC database

The starting point of the tool is a database with vessel information. This database contains the following information for each vessel financed by NIBC [?]:

- Vessel name
- vessel-type
- Dead weight tonnage (DWT)
- Building year
- Ballast water pump capacity
- Last known survey

This list contains all the required data to execute the tool. For some vessels, the ballast water pump capacity is unknown. For these vessels, a calculation is used to determine the ballast water pump capacity based on the DWT and vessel-type. This approach is discussed in section 2.1.3.
As the portfolio of NIBC changes over time this database has to be updated.

7.4.2. Vessel values, Time Charter (T/C) rates and Operating expenditure (Opex)

The input of T/C rates, vessel values and Opex are gathered from research and consulting firm MSI [?] [1]
As MSI [?] publishes this data on a quarterly basis, the model should be updated every quarter. The values published by MSI are all nominal values. This implies that these values are not adjusted for the time value of money. However, the time value of money is taken into account by the net present value calculation.
The MSI data used as input for the tool, is shown in table 7.2. This table shows the output from MSI, which is the input for the tool. This data contains:

- Vessel values for different DWTs, vessel-types, ages and for different moments in time (1980-2035).
- T/C rates for different DWT and vessel-types and for different moments in time (1980-2035).
- Opex for different DWT and vessel-types and for different moments in time (1980-2035)

The vessel-types defined in the NIBC database are more specific on oil tankers compared to MSI [?]. The oil tankers from the MSI database are split up in product and crude tankers in the NIBC database.

Vessel value
The vessel value is calculated by interpolating between the vessel values from MSI. In this way, vessel values of all sizes and age can be calculated for every moment in time and for every vessel-type. These values are used to lookup the value of the vessel today and at the end of its lifetime. These values are used in the cash flow modes and will be discussed in section 7.6.

T/C rates
Time charter rates are the total voyage revenues in a year minus the voyage expenses. The T/C rates are calculated by interpolating between the T/C rates from MSI. This results in a forecast of T/C rates for a specific vessel for its entire lifetime. These yearly forecasted T/C rates are used in the vessel-specific cash flow models. How these rates are used will be explained in more detail in section 7.6.

[1] "MSI Ltd., a research and consulting company, provides market forecasting and business advisory services for shipping and its allied industries. It offers market reports for dry bulk, tanker, container, liquefied natural gas, cruise, shipbuilding, and offshore sectors, as well as ship operators; and market forecasting models and regular vessel valuations. The company also provides consulting services, such as project evaluation, trade and market share projections, market research/surveys, financing and investment prospectuses, fleet portfolio reviews, market risk and sensitivity studies, expert testimony/litigation support, strategic market positioning, and vessel size and route evolution; and international macroeconomic forecasting, credit risk modeling, transportation logistics, and shipping and project financing services. It serves financial institutions, ship owners, shipyards, brokers, investors, insurers, and equipment and service providers. MSI Ltd. has a strategic partnership with Infield Systems Ltd. The company was founded in 1985 and is based in London, United Kingdom with an office in Singapore." [?]

vessel-type	DWT	Vessel value	Time charter	Opex
Container ships	1050 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	1700 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	2050 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	3400 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	4300 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	5000 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	6750 TEU	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
Oil tankers	32500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	45000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	70000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	112500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	145000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	280000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
Dry Bulk carriers	32500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	47500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	70000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	165000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
Chemical tankers	5500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	8500	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	17000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	20000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	25000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	33000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	45000	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
LPG carriers	5000 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	7000 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	12500 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	20000 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	37500 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	56000 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX
	81500 m^3	Vessel value(0/5/10/15/20 years old)	T/C rate	OPEX

Table 7.2: MSI data input [**?**]

Opex
The Opex or Operating expenditure which is used in the tool includes the following costs:

- Crew (includes both direct and indirect crew costs (ie. salary, pension, medical, crew travel, victualling, overtime and training) [**?**]
- Lubes and Stores (includes lube oils, spare parts, tools, deck and engine room supplies) [**?**]
- Insurance (includes H&M and P&I) [**?**]
- Repair and Maintenance (including routine maintenance, classification fees and provisions for 5 year special survey and dry-docking.) [**?**]
- Administration (includes allowance for management, communications and shore base support services) [**?**]

Note that the Opex does not include voyage expenditure as this is already taken into account with the time charter rates. The Opex can be calculated by interpolating between the Opex from MSI. This results in a forecast in Opex for a specific vessel for its entire lifetime. This yearly forecasted Opex is used in building the cash flow model. This will be explained in more detail in section 7.6.

7.4.3. Ballast water treatment purchase and installation prices

The ballast water treatment system purchase and installation costs are known for 10 different suppliers with multiple ballast water pump capacities. A database of 79 ballast water treatment systems is created with ballast pump capacities ranging from 150 to 7200 m^3/h. This input consists of:

- The ballast water treatment method
- The BWT manufacturer
- The ballast water pump capacity (m3/h)
- The BWT system cost
- Engineering and installation cost Europe
- Engineering and installation cost China
- The Opex of the system

As the ballast water pump capacity is known, or calculated, the required capacity for the ballast water treatment system can be matched. It is assumed that the ballast water treatment capacity is at least as big as the ballast water pump capacity. From each of the 10 ballast water treatment suppliers, the system with the minimum required pump capacity is selected. This creates a list of 10 possible solutions as shown in figure **??**. When one of the systems can not supply the capacity demand of this vessel, the cells are left empty. This can be seen in the example in figure **??** where the "DESMI UV" system is not able to supply enough capacity.
FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS
From this list of 10 possible systems, the most and least expensive systems are filtered out. This is done to filter out the extreme cases. As discussed in chapter 5 some manufacturers show extreme prices for some capacity range. The second reason is the fact that some manufacturers will not provide a BWT system with the exact required capacity. In figure **??** it is shows that the Coldharbour inert gas system only supplies a 2,400 m3/h system which is priced twice as high compared to the other systems available. This is resolved by filtering out the two most extreme cases resulting in a sensitivity analysis. From the remaining 8 possible systems the most and least expensive systems are selected and used as the low-price and high-price system respectively. This means that from the available list of 10 systems, the second least and second most expensive systems are selected to be used. These two systems are used to show the range in which the system can be bought, engineered and installed.

For this specific example, the low-price and high-price system that are used are shown in figure **??**.

7.4.4. LIBOR

The LIBOR rate is the benchmark interest rate for banks. Historic LIBOR rates and forecast rates from 1990 to 2026 are used as input [?]. In the cash flow model the end-of-the year LIBOR rate is used as it is assumed that the interest has to be paid at the end of the year. The LIBOR rate together with the NIBC margin form the total interest rate for the ship owner to pay. This total interest rate is referred to as *"total debt service"*.

7.4.5. The IMO going into-force date

The IMO going-into-force date is set on the 8^{th} of September 2017. This date is set as a variable in the tool. When the IMO decides to postpone the implementation date, this can easily be adjusted.

7.4.6. IOPP additional cost

The renewal of the IOPP certificate before the going-into-force date is an option to postpone the implementation for a maximum of 5 years. The cost of this renewal, including the de-harmonisation and harmonisation after 5 years is set on $6.500 [?] according to DNV-GL. This price is independent on the vessels' type and size as this action requires mainly paperwork.

7.4.7. Cost for installation at IOPP renewal

The renewal of the IOPP certificate gives the ship owner the opportunity to delay the installation date. Preparation in dry-dock is not necessary and the entire installation can take place just before the next IOPP renewal. The extra cost of installation without preparation in dry-dock is set at 10%. This assumption is made to penalize the fact of not preparing the piping when the vessel is in dry-dock. When the vessel would be in dry-dock, installation is considered more easy because the vessel can be accessed more efficiently. The price of the system itself stays the same.

7.5. Input variables

The input variables are the variables that the tool will be running on, which can be easily adjusted. The table below shows which variables can be changed to run the model, followed by a description of each variable.

Variable	**Description**
Amortization profile	Economic vessel lifetime
Cash reserve	The available liquidity of the owner to cover cash out in a bad market
Increase in Opex	Yearly Opex cost increase
Decrease in T/C rate	Yearly decrease in T/C rate
Time period for histogram	Time period in which to create a histogram with T/C rates
Discount rate	Discount rate

Table 7.3: Variables used in the tool with brief description

Vessel lifetime

The lifetime of each vessel is conservatively assumed to be 20 years. This is based on the fact that charterers have set an age restriction on the vessels that usually averages 20 years. Furthermore special surveys get more expensive when a vessel gets older due to wear and tear while the vessel value depreciates. MSI therefore assumes the value of a 20 years old vessel equal to the scrap value. The bank considers a loan for vessels up to 15 years old. When the vessel is in default with the loan agreement, the bank considers a 5 year run out. This is done to keep the loan within the assumed 20 years lifetime of the vessel. This is a rather conservative approach as the actual lifetime of a vessel can be more than 20 years.

Increase in Opex cost and decrease of T/C rates

A yearly increase in Opex cost can be implemented. This is done to simulate the fact that the Opex can increase due to the ageing of the vessel. On the other hand a yearly decrease in T/C rates can be set. This is also done to simulate the fact that charterers are willing to pay more for a new-build vessel compared to an older vessel, as explained in section 7.6. For further calculations, both values are set to zero.

Time period to create an accumulated histogram for T/C rates
Because historic and forecasted T/C rates are known, an accumulated histogram can be created to show the probability of occurrence within a given period of time. The time range in which this histogram is created can vary between 1980 and 2025. This is used in the output, as shown in section 7.9.

USCG approval
This thesis is about the impact of the IMO ballast water treatment convention. As discussed before, the USCG has set stricter regulations and an early IOPP renewal will not be a feasible strategy. By ticking the *"USCG approval"* box in the tool, all calculations will be calculated based on USCG approval.

7.6. Tool calculations

This section shows the calculations of the tool that will generate the output. The tool operates on a lot of input data which is previously discussed in section 7.4. This input data will be referred to further in this chapter. The calculation of the tool starts with the input of a vessel name from the NIBC portfolio. Whenever a vessel name from the database is entered, it will follow the steps and calculation shown below. The excel tool makes use of colour codes. Yellow means that this cell contains an input and blue cells imply a calculated or lookup value. The process of the tool can be split up in 13 main calculations, an overview of the steps is shown in table 7

Step nr.	Brief description
1	Vessel name is entered, lookup vessel information from NIBC database
2	Calculate vessel age
3	Calculate years left to sail
4	Lookup suitable low-price and high-price BWT system
5	Calculate the vessel value today and for end of lifetime for all different strategies
6	Calculate the vessel-specific T/C rate and Opex for the lifetime of the vessel
7	Compare current T/C rate with the historic and forecasted rates in the accumulated histogram
8	Create a cash flow model for each strategy
9	Calculate the required freight rate (RFR)
10	The current vessel value is used as an investment in the cashflow model
11	Table is created to compare the different strategies
12	The IRR is calculated for each strategy
13	The maximum loan to value LTV is calculated

1. The tool starts the calculations when entering a vessels' name. With the use of a lookup function the vessel-type, DWT, building year, ballast pump capacity and last known survey are retrieved from the NIBC database, as discussed in section7.4.1. The next survey is then calculated by adding 5 years to the last known survey. This can be seen in figure **??**. The last known survey is set to be the anniversary date of the vessel. Three months prior and three months after the anniversary date an IOPP renewal can be executed. This timespan is calculated by adding and subtracting three months from the anniversary date. This data is used to determine whether the vessel can perform certain strategies like an early IOPP renewal.

   FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS

2. The age of the vessel is calculated:

$$Vessel\ age = current\ year - building\ year \tag{7.1}$$

   The age is used for calculating both the years left to sail and the value of the vessel.

3. The years left to sail according to the vessel's lifetime are calculated:

$$Years\ left\ to\ sail = Life\ time\ expectancy - vessel\ age \tag{7.2}$$

   The years left to sail will be used in order to know until which year the cash flow model has to be produced.

4. The ballast water treatment system purchase and installation price are retrieved from the ballast water treatment systems input. The price of the second highest and lowest price is returned as shown in figure **????**.

   FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS

   Both of these prices are used for the low-price and high-price investment in the cash flow model.

5. The value of a vessel is calculated by looking at the known vessel age, DWT and vessel-type 7.4.1. The MSI input 7.4.2 shows vessel values for multiple DWTs for the age of: 0,5,10 and 20(scrap) for each vessel-type. By interpolating between the 5 year age buckets that MSI [**?**] uses, vessel values can be calculated for every age. This creates a table with vessel values for multiple DWTs and every age as shown in figure 7.1.

Years old	DWT	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0	32500	23.0	20.6	20.9	23.6	21.3	19.4	18.7	18.2	18.8	20.5
1	32500	22.8	19.9	20.2	22.8	19.6	17.4	17.6	17.3	17.9	19.6
2	32500	22.7	19.1	19.6	22.0	18.0	15.3	16.4	16.3	16.9	18.7
3	32500	22.5	18.4	18.9	21.1	16.3	13.2	15.3	15.3	16.0	17.8
4	32500	22.3	17.7	18.3	20.3	14.7	11.2	14.1	14.3	15.1	16.9
5	32500	22.2	16.9	17.6	19.4	13.0	9.1	13.0	13.3	14.1	16.0
6	32500	21.2	16.1	16.7	18.4	12.3	8.5	12.0	12.4	13.4	15.2
7	32500	20.3	15.3	15.8	17.4	11.5	7.9	11.0	11.5	12.7	14.5
8	32500	19.4	14.5	14.8	16.3	10.7	7.3	9.9	10.5	12.0	13.7
9	32500	18.4	13.7	13.9	15.3	9.9	6.7	8.9	9.6	11.3	12.9
10	32500	17.5	12.8	13.0	14.3	9.1	6.2	7.9	8.7	10.6	12.1
11	32500	16.9	11.9	12.0	13.4	8.4	5.6	7.3	8.1	9.9	11.5
12	32500	16.2	11.0	11.0	12.5	7.6	5.1	6.7	7.5	9.2	10.9
13	32500	15.6	10.1	10.0	11.7	6.9	4.6	6.1	6.9	8.5	10.2
14	32500	14.9	9.2	9.0	10.8	6.2	4.1	5.5	6.3	7.8	9.6
15	32500	14.3	8.3	8.0	9.9	5.5	3.6	4.9	5.7	7.1	9.0
16	32500	12.2	7.4	7.1	8.7	4.9	3.3	4.4	5.0	6.1	7.6
17	32500	10.2	6.4	6.1	7.5	4.4	2.9	3.8	4.3	5.1	6.3
18	32500	8.1	5.4	5.2	6.3	3.9	2.6	3.3	3.5	4.2	5.0
19	32500	6.1	4.5	4.3	5.0	3.4	2.3	2.8	2.8	3.2	3.6
20	32500	4.0	3.5	3.4	3.8	2.8	1.9	2.3	2.1	2.2	2.3
0	47500	29.7	25.0	24.9	28.0	25.2	22.1	21.0	20.2	21.4	24.4
1	47500	29.2	24.3	24.1	27.3	23.3	20.2	19.8	19.3	20.4	23.3
2	47500	28.7	23.7	23.3	26.6	21.5	18.2	18.7	18.3	19.4	22.2
3	47500	28.2	23.0	22.4	25.9	19.6	16.2	17.5	17.4	18.5	21.2
4	47500	27.7	22.3	21.6	25.2	17.7	14.2	16.3	16.4	17.5	20.1
5	47500	27.2	21.6	20.8	24.4	15.8	12.2	15.2	15.4	16.5	19.1

Figure 7.1: The vessel values for bulk carriers are calculated for every age, ranging from 0 to 20 (scrap price) for different DWTs for every point in time from 2011 until 2035.(Figure shows part of the entire table)

By interpolating between the DWT, vessel values of all sizes and age can be calculated for every moment in time. Different strategies can end in different points in time. Figure 7.2 shows the vessel value for different ages in different points in time for each strategy. The prices can be calculated from 2011 until 2045.

Years old		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
3	Vessel price	24.1	19.3	18.9	20.9	16.0	13.3	14.8	14.7	15.5	17.8
20	Vessel scrap price	4.0	3.7	3.6	4.0	3.0	2.0	2.4	2.2	2.4	2.4
5.00	Vessel price	23.9	18.2	17.7	19.4	12.8	9.7	12.8	12.9	13.8	16.0
8.00	Vessel price	21.1	15.6	15.2	16.5	10.5	7.6	10.2	10.7	11.8	13.7
10.00	Vessel price	19.3	13.8	13.5	14.6	9.0	6.1	8.5	9.2	10.4	12.1
15.00	Vessel price	15.2	9.1	8.2	9.9	5.7	3.4	5.5	6.1	7.4	9.3

Year	Year	Year	Year	Year
2017	2019	2022	2027	2032
Years old	Years old	Years old	Years old	Years old
3	5.00	8.00	10.00	15
Vessel Price	Vessel Price	Vessel Price	Vessel Price	Vessel price
$ 14.83	$ 13.78	$ 14.69	$ 19.77	$ 12.79
Scrap Price				
$ 2.38				

Figure 7.2: The vessel value calculated over time. Including prices and forecasts from 2011 until 2045.

When a strategy implies that the vessel is going to be sold or scrapped, a discount on the vessel price is used. The vessel prices from MSI [**?**] are based on vessels in operable condition. This implies that the vessel should have a ballast water treatment system when required. When no ballast water treatment system is installed, the following formula is used to create a discount:

$$Vessel\ value\,(without\ BWT) = MSI\ vessel\ value - average\ BWT\ investment \tag{7.3}$$

If the vessel value is smaller than the scrap value of the vessel, the scrap price is used. This discount is used to ensure a fair selling price.

6. The vessel-specific T/C rate and Opex is calculated by interpolating between the DWT of the T/C rate and Opex input. The T/C rates and Opex can be calculated from 1980 to 2035 for every vessel-type and DWT. With the input variables, *"Increase of Opex"* and *"decrease of T/C rate"*, the Opex can be increased by a given percentage. Likewise, the T/C rate can be decreased by a given percentage on a yearly basis. This option is built in to simulate the fact that demand for old ships will be lower. When a vessel ages, the Opex is expected to increase. In this research it is assumed that rates and/or Opex do not change. Both the increase of Opex and the decrease of T/C rates are set at 0%. Figure 7.3 shows the forecast of vessel-specific T/C rates and Opex which are used.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1 year T/C rate	$ 7.63	$ 6.79	$ 3.73	$ 3.48	$ 3.38	$ 4.95	$ 4.26	$ 6.36	$ 10.70	$ 11.78	$ 7.34
Opex	$ 3.51	$ 3.66	$ 3.83	$ 3.79	$ 3.76	$ 3.70	$ 3.59	$ 3.53	$ 3.61	$ 3.66	$ 3.78
Net earnings	$ 4.92	$ 3.97	$ 0.78	$ 0.57	$ 0.49	$ 0.63	$ 0.07	$ 2.23	$ 6.48	$ 7.49	$ 3.56

Figure 7.3: Forecast of T/C rates and Opex for a specific vessel-type and size. Including prices and forecasts from 1980 until 2035

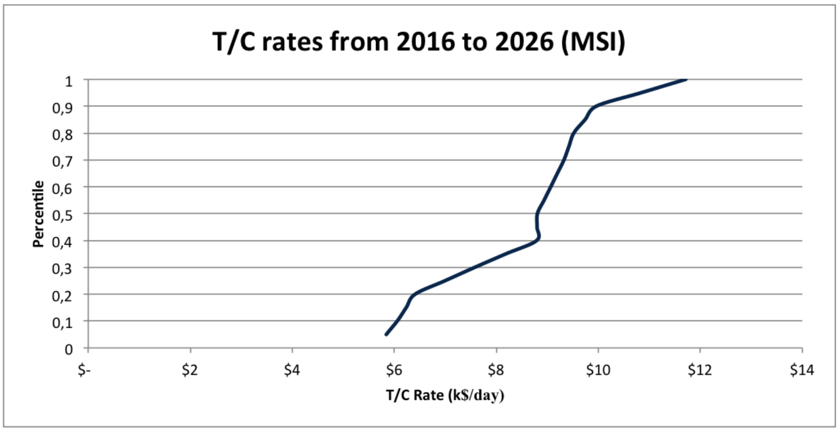
7. With the historic and forecasted T/C rates, an accumulated histogram is created. Figure 7.4 shows the percentage of occurrence over a given period of time. The percentiles show that, in this example, rates of $ 8,790 or lower are expected to occur 40% of the time between 2016 and 2026. This implies that in 60% of the cases the rates will be higher. This is used to show the current market compared to historic and/or future forecasted rates.

8. With the previous calculations, a cash flow model can be created for all different strategies. Figure 7.5 shows an example for one of the cash flow models, in this case for strategy 17. A detailed description on how the cash flow model is built up with the previous calculations can be found in section 7.7. This is done for every strategy and with a maximum lifetime of 20 years.

From Year	To Year
2016	2026

Rate k$ (day)		Percentile
$	6.50	0.05
$	7.37	0.10
$	7.51	0.15
$	7.64	0.20
$	7.82	0.25
$	8.00	0.30
$	8.56	0.35
$	9.12	0.40
$	9.14	0.45
$	9.16	0.50
$	9.29	0.55
$	9.42	0.60
$	9.47	0.65
$	9.52	0.70
$	9.68	0.75
$	9.83	0.80
$	10.01	0.85
$	10.20	0.90
$	11.08	0.95
$	11.96	1.00

(a) Percentiles calculated



(b) Visualisation of the percentiles

Figure 7.4: Percentiles for buckets of 5% created from forecast values from 2016 until 2026.

9. The BFR, break-even freight rates are calculate [**?**]. For this calculation it is assumed that all capital comes from the ship owner. This implies that the required freight rate can be calculated by dividing the sum of the total cash flow, excluding freight rate, by the time period as shown in equation 7.4.

$$
\begin{aligned}
BFR &= \frac{-C_o + \sum_{t=1}^{T} C_t}{T} \\
BFR &= Break-even\ freight\ rate \\
C_t &= Net\ cash\ flow\ during\ period\ t \\
t &= Time\ period \\
T &= Total\ time\ period \\
C_o &= Initial\ investment\ (vessel\ value)
\end{aligned}
\tag{7.4}
$$

The break-even freight rate is the rate that the vessel has to earn to get to the break-even level before the end of its lifetime (20 years). This means that when the rate is higher than the required freight rate, the owner can make a profit.

10. Every vessel is looked at from a perspective of a new investment. It is assumed that the owner makes the decision to sail with the vessel instead of making a direct sale. The current vessel value is used as the initial investment. At the end of the project, the forecasted value of the vessel at that specific moment in time is used as an income. This is done because the decision is made now and not assumed to be influenced by the past. Besides that, the vessel is taken as an investment because it can be sold for that price at that moment.

Strategy 17							
		2017	2018	2019	2020	2021	2022
Forecast T/C rate pessimistic		$ 2,556,819	$ 2,649,583	$ 2,774,155	$ 3,174,933	$ 3,407,804	$ 3,265,454
Forecast T/C rate base case		$ 2,691,388	$ 2,789,034	$ 2,920,163	$ 3,342,034	$ 3,587,162	$ 3,437,320
Forecast T/C rate optimistic		$ 2,825,957	$ 2,928,486	$ 3,066,171	$ 3,509,136	$ 3,766,520	$ 3,609,186
Forecast Opex		$ (1,669,458)	$ (1,686,125)	$ (1,712,223)	$ (1,758,759)	$ (1,806,214)	$ (1,827,427)
Forecast Opex low end		$ -	$ -	$ -	$ -	$ -	$ (2,125)
Forecast Opex high end		$ -	$ -	$ -	$ -	$ -	$ (2,125)
RFR for low-end		$ 2,648,169	$ 2,648,169	$ 2,648,169	$ 2,648,169	$ 2,648,169	$ 2,648,169
RFR for high-end		$ 2,686,879	$ 2,686,879	$ 2,686,879	$ 2,686,879	$ 2,686,879	$ 2,686,879
TC rate forecast		$ 2,691,388	$ 2,789,034	$ 2,920,163	$ 3,342,034	$ 3,587,162	$ 3,437,320
RFR without system		$ 2,618,924	$ 2,618,924	$ 2,618,924	$ 2,618,924	$ 2,618,924	$ 2,618,924
Surplus BWT low		$ 27,744	$ 27,744	$ 27,744	$ 27,744	$ 27,744	$ 27,744
Surplus BWT high		$ 66,454	$ 66,454	$ 66,454	$ 66,454	$ 66,454	$ 66,454
Vessel value		$ (14,832,833)					
Scrap Price		$ -	$ -	$ -	$ -	$ -	$ -
Opex		$ (1,669,458)	$ (1,686,125)	$ (1,712,223)	$ (1,758,759)	$ (1,806,214)	$ (1,827,427)
Extra IOPP cost		$ (6,500)	$ -	$ -	$ -	$ -	$ -
Low-end BWT		$ -	$ -	$ -	$ -	$ -	$ (465,149)
OPEX low-end		$ -	$ -	$ -	$ -	$ -	$ (2,125)
High-end BWT		$ -	$ -	$ -	$ -	$ -	$ (1,123,218)
OPEX high-end		$ -	$ -	$ -	$ -	$ -	$ (2,125)
Total Cash flow low-end		$ (13,860,622)	$ 962,044	$ 935,946	$ 889,409	$ 841,954	$ 353,468
Total Cash flow high-end		$ (13,821,912)	$ 1,000,754	$ 974,656	$ 928,119	$ 880,664	$ (265,892)
Total Cash flow no BWT		$ (13,883,366)	$ 932,800	$ 906,702	$ 860,165	$ 812,710	$ 791,497
$	(14,832,833)	$ 880,861	$ 963,458	$ 1,061,932	$ 1,416,173	$ 1,601,590	$ 970,754
		$ (13,951,959)	$ (12,988,504)	$ (11,926,576)	$ (10,510,410)	$ (8,908,830)	$ (7,938,083)
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$	(14,832,833)	$ 1,015,430	$ 1,102,909	$ 1,207,940	$ 1,583,275	$ 1,780,948	$ 1,142,620
		$ (13,817,389)	$ (12,714,483)	$ (11,506,548)	$ (9,923,281)	$ (8,142,344)	$ (6,999,733)
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$	(14,832,833)	$ 1,150,000	$ 1,242,361	$ 1,353,948	$ 1,750,376	$ 1,960,306	$ 1,314,486
		$ (13,682,820)	$ (12,440,463)	$ (11,086,520)	$ (9,336,152)	$ (7,375,858)	$ (6,061,382)
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$	(14,832,833)	$ 880,861	$ 963,458	$ 1,061,932	$ 1,416,173	$ 1,601,590	$ 312,684
		$ (13,951,959)	$ (12,988,504)	$ (11,926,576)	$ (10,510,410)	$ (8,908,830)	$ (8,596,148)
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$	(14,832,833)	$ 1,015,430	$ 1,102,909	$ 1,207,940	$ 1,583,275	$ 1,780,948	$ 484,550
		$ (13,817,389)	$ (12,714,483)	$ (11,506,548)	$ (9,923,281)	$ (8,142,344)	$ (7,657,797)

Figure 7.5: Cash flow model of strategy 17. Shows the six cash flow models for strategy 17. It shows the cash flow for the three cases: Pessimistic, Base case and Optimistic all for a low-price and a high-price ballast water treatment system.

11. For all the strategies an overview as shown in figure 7.6 is created with the cash flow models. First the feasibility of all strategies for this specific vessel is verified. If the strategy is not feasible because of the anniversary date of the vessel, the second column will show *"FALSE"* and no further rates are disclosed. This influences the output. When it not feasible to execute a strategy for a certain vessel, no output will be shown.

Strategy	Feasibility	Total investment cost	RFR scrap	RFR No BWT	RFR BWT	Payback (years) Pessimistic case	Payback (years) Base Case	Payback (years) Optimistic case
1								
2	TRUE	$ (465,147)		$ 7.18	$ 7.26	11	10	10
2	TRUE	$ (1,123,215)		$ 7.18	$ 7.36	11	11	10
3	TRUE	$ (465,147)		$ 7.18	$ 7.26	11	10	10
3	TRUE	$ (1,123,215)		$ 7.18	$ 7.36	11	11	10
4	FALSE	$ -	$ -			99	99	99

Figure 7.6: List of strategies with required freight rates.

12. The IRR, Internal Rate of Return is *"the percentage rate earned on each dollar invested for each period it is invested."* [**?**]. This is the discount rate in the Net Present value that makes the NPV, of the total cash flow, equal to zero 7.6. This makes it possible to compare different investments with each other [**?**]. Equation 7.5 shows the net present value formula. The IRR is calculated in equation 7.5 where the NPV is equal to zero. The IRR calculation is an iterative calculation which in this case is calculated with the use of *Microsoft Excel*.

$$
\begin{aligned}
NPV &= \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_o \\
NPV &= Net\ present\ value \\
C_t &= Net\ cash\ flow\ during\ period\ t \\
IRR &= Internal\ rate\ of\ return \\
t &= Time\ period \\
C_o &= Initial\ investment
\end{aligned}
\tag{7.5}
$$

13. The maximum LTV, loan to value, can be calculated with the cash flow models as well. The loan to value is important for the bank as it shows the maximum debt service which the borrower is able to pay with the forecasted cash flow models. It is assumed that the loans can vary from 10% to 100% in 10% increments. This means that there are 10 feasible loans: 10%, 20%, 30%, etc. The total debt service, which is the amortization and the total interest to be paid to the bank, can be calculated for all feasible loans. This debt service is then implemented in the cash flow model which checks whether the debt service can be paid with the forecasted cash flow of the vessel. This is done for the three feasible scenarios of the base case forecast and for a high-price and low-price BWT system. This is an important figure for the bank as it represents the solvency of its client.

    With the coming of Basel III requirements, banks are required to hold more capital to mitigate against risk of a financial crisis [**?**]. This implies that the margins will go up as the cost of capital of the bank will go up was well. This can cause a negative impact on the maximum LTV. In this report this is not taken into account, but it should be noted that this can have an influence on the outcome. A more detailed explanation on the loan implementation in the tool can be found in section 7.8.

7.7. The cash flow models

The cash flow models that are created with the previous calculations will now be discussed. It is important to know that multiple cash flow models in the tool are combined in order to prevent duplicates. Every strategy has its own cash flow model. There are six strategies which are economically interesting when assumed that the price of ballast water treatment systems remain stable. All six strategies can have one of the following scenarios:

- Install a BWT system (high-price and low-price)
- No BWT system needed
- Sell or Scrap the vessel

These scenarios are then calculated for different cases: pessimistic case, base case and an optimistic case. This implies that the strategies within the *sell/scrap* and *No BWT system needed* scenario contain three cash flow models. For the strategies that install a ballast water treatment system, the cash flow model will actually contain six different cash flow models, because of the high-price and low-price BWT system, as shown in figure 7.5. To calculate the impact of the ballast water treatment system, a hypothetical scenario where no ballast water treatment is installed is also calculated. The build-up of the cash flow models for each different strategy will be discussed in this section.
All the cash flow models can be built-up with the cash-in and cash-out as shown in table 7.4.

Cash flow	Description
Forecast T/C rate	This is the nominal T/C rate income forecast from MSI for every year in three different cases: pessimistic, base case and optimistic. (7.4.2)[**?**]
Forecast Opex	This is the nominal Opex forecast from MSI for every year(7.4.2)[**?**]
Forecast Opex BWT system	This is the fixed Opex for a low-price or high-price ballast water treatment system. This is a yearly cost from the moment that the total ballast water treatment system is installed(7.4.3).
Vessel value	This is today's vessel value, this is assumed to be a one time investment
Sell/scrap price	This is the nominal vessel's value income at the end of the vessel's lifetime. The lifetime depends on the vessel's age and the strategy that is followed (7.4.2)
IOPP renewal	This is the cost for an IOPP renewal (7.4.6, this is a one time investment
Investment BWT solution	This is the investment cost of the a low-price or high-price ballast water treatment system. This is a one time investment (5.1).
Total Cash flow	This is the total Cash flow which is calculated, depending on the strategy as shown in equation 7.6. The total cash flow is calculated for every strategy, the three different cases (pessimistic, base case and optimistic) and two different BWT prices (low-price and high-price).
IRR	This is the Internal Rate of Return of the initial investment of the vessel and the total cash flow that follows. This is again calculated for every strategy, the three cases and two different BWT prices.

Table 7.4: Overview of the cash-in and cash-out to build the cash flow models

Equation 7.6 shows how the total cash flow is build up. As in with accounting, the negative values are shown between brackets while the other values are positive.

$$\begin{aligned} Total\,Cash\,flow = \; & Forecast\,T/C\,rate\,(pessimistic/basecase/optimistic) * (part\,of\,year\,left\,to\,sail) \\ & + forecast\,Opex \\ & + (Vessel\,value) \\ & + (IOPP\,renewal) \\ & + (Investment\,BWT\,system\,(low-price/high-price)\,solution\,) \\ & + (Forecast\,Opex\,BWT\,system\,(low-price/high-price)) \\ & + Sell/Scrap\,value \end{aligned} \tag{7.6}$$

The cash flow model is created for the ship owner. This implies that the following figures are positive (income) or negative (cost):

- T/C rate pessimistic/base case/optimistic (positive value, the owner receives this rate from the charterer)
- Opex (negative value, the operational expenditures are for the ship owner as the cash flow model is based on time charter rates)
- IOPP renewal (negative value, these costs are for the ship owner)
- Preparation depreciation BWT system low-price/high-price solution (negative value, these costs are for the ship owner as he has to make sure the vessel is sailing. Without the installation of a ballast water treatment solution the vessel is not operable)
- Finishing depreciation BWT system low-price/high-price solution (negative value, same reasoning as with preparation cost)
- Forecast Opex BWT system low-price/high-price (negative value, note that this does not include fuel expenditure as this is in charge of the charterer)
- Sell/Scrap value (positive value, when the vessel is sold or scrapped, this belongs to the owner)

7.7.1. Cash flow model length of operation

The length, in years, of the cash flow model is determined by the strategy. With the vessel specifications from the NIBC database 7.4.1 the years left to sail for a specific strategy are calculated. Table 7.5 shows the equation for each strategy.

Strategy	Equation end of operation
2 & 22	$Project\ duration\ in\ years\ (set\ at\ 20\ years) - (Year\ today - Building\ year)$
5	$Project\ duration\ in\ years\ (set\ at\ 20\ years) - (Year\ today - Building\ year)$
17	$Project\ duration\ in\ years\ (set\ at\ 20\ years) - (Year\ today - Building\ year)$
4	$Date\ Next\ dry-dock + 5\ years$
16	$Date\ Next\ survey + 5\ years$
21	$Date\ Next\ survey - Year\ today$

Table 7.5: Years left to sail equations for the different strategies

For the strategies 4, 16 and 21, which are *Sell/Scrap* or *No BWT needed* scenarios, the rule is set that when the end date is larger than the lifetime of the vessel, the lifetime of the vessel is used.
As can be seen from the equations in table 7.5 it is assumed that strategies 2 & 22, 5 and 17 will stop operating at the end of the year (December 31) and lifetime of the vessel. Whereas strategies 4, 16 and 21 will end at a specific date. This is an important date because these vessels will no longer be in compliance with the IMO/USCG regulation. This changes the "Total Cash flow" calculation. For these strategies the "Total Cash flow" equation in the last year of operation looks as follows:

$$
\begin{aligned}
Total\ Cash\ flow = {} & Forecast\ T/C\ rate * (part\ of\ year\ left\ to\ sail) \\
& + (forecast\ Opex * (part\ of\ year\ left\ to\ sail)) \\
& + (Vessel\ value) \\
& + (IOPP\ renewal) \\
& + Sell/Scrap\ value
\end{aligned}
$$

This cash flow calculation takes into account that the vessel only operates for part of the entire year.

7.8. Loan to value

The loan to value is the percentage of the loan amount divided by the vessel value. The higher the loan, the higher the internal rate of return can be for the owner of the vessel. This is the fact when the return on the vessel is higher than the interest on the loan. For the *Install a BWT system* scenario the feasible loan is calculated. The repayment profile of the loan is set at 15 years for a new-build vessel. For older vessels the repayment profile is set to end at an age of 15.

The amortization time for the loan is set at 15 years as this is the maximum age in which a bank wants to provide liquidity.
Figure 7.7 shows an example of the low-price BWT system. The top part of the cash flow model is identical to the cash flow model discussed before in section 7.7. The bottom part is the implementation of the loan. Everything between two double thin lines represents the total cash flow for each loan amount. The top row for each loan amount shows the % LTV and the total debt service which has to be paid on a yearly basis.
The debt service is built up by the following costs:

- LIBOR (the forecasted LIBOR is used as discussed in 7.4.4.)
- NIBC margin (the NIBC margin is set at 3% for all loans. This is the current average margin of the bank.)
- Amortization (the amortization is set at a maximum repayment profile of 15 years. This implies that the amortization is the total loan amount divided by the number of years left for repayment. The amortization is set at 15 years as this is a common repayment profile that the bank uses.)

Scenario's No BWT

				2017		2018		2019		2020		2021
	Pessimistic TC rate		$	4,366	$	5,251	$	6,060	$	6,963	$	6,349
	Base case TC rate		$	4,596	$	5,513	$	6,363	$	7,311	$	6,666
	Optimistic TC rate		$	4,826	$	(2,371)	$	(2,408)	$	(2,473)	$	(2,539)
	Opex		$	(2,349)	$	(2,371)	$	(2,408)	$	(2,473)	$	(2,539)
	Vessel value		$	(26,917)	$	-	$	-	$	-	$	-
	Sell / Scrap price		$	-	$	-	$	-	$	-	$	-
	Preparation BWT		$	-	$	-	$	-	$	-	$	-
	Finish BWT		$	-	$	-	$	-	$	-	$	-
	IOPP		$	-	$	-	$	-	$	-	$	-
	Opex BWT		$	-	$	-	$	-	$	-	$	-
	Base case cashflow		$	2,247.06	$	3,141.66	$	3,954.38	$	4,837.83	$	4,126.73
	Base case cashflow owner		$	(24,670)	$	3,142	$	3,954	$	4,838	$	4,127
Feasilble?	**100%**		$	(3,422)	$	(3,437)	$	(3,390)	$	(3,273)	$	(3,189)
	Base case		$	(675)	$	(295)	$	564	$	1,564	$	938
FALSE	**Sum debt service**		$	(675)	$	(970)	$	(406)	$	1,159	$	2,097
Total cashflow	$	-	$	(1,175)	$	(295)	$	564	$	1,564	$	938
IRR				0%								
	90%		$	(3,080)	$	(3,093)	$	(3,051)	$	(2,946)	$	(2,870)
	Base case		$	(333)	$	49	$	903	$	1,892	$	1,257
FALSE	**Sum debt service**		$	(333)	$	(284)	$	619	$	2,511	$	3,768
Total cashflow	$	(2,692)	$	(832.89)	$	48.77	$	903.25	$	1,891.77	$	1,256.75
IRR				0%								
	80%		$	(2,738)	$	(2,749)	$	(2,712)	$	(2,619)	$	(2,551)
	Base case		$	9	$	392	$	1,242	$	2,219	$	1,576
TRUE	**Sum debt service**		$	9	$	402	$	1,644	$	3,863	$	5,439
Total cashflow	$	(5,383)	$	(490.68)	$	392.42	$	1,242.26	$	2,219.11	$	1,575.63
IRR				23%								
	70%		$	(2,396)	$	(2,406)	$	(2,373)	$	(2,291)	$	(2,232)
	Base case		$	352	$	736	$	1,581	$	2,546	$	1,895
TRUE	**Sum debt service**		$	352	$	1,088	$	2,669	$	5,215	$	7,110
Total cashflow	$	(8,075)	$	(148.46)	$	736.08	$	1,581.28	$	2,546.45	$	1,894.52
IRR				20%								
	60%		$	(2,053)	$	(2,062)	$	(2,034)	$	(1,964)	$	(1,913)
	Base case		$	694	$	1,080	$	1,920	$	2,874	$	2,213
TRUE	**Sum debt service**		$	694	$	1,773	$	3,694	$	6,568	$	8,781
Total cashflow	$	(10,767)	$	194	$	1,080	$	1,920	$	2,874	$	2,213
IRR				18%								
	50%		$	(1,711)	$	(1,718)	$	(1,695)	$	(1,637)	$	(1,594)
	Base case		$	1,036	$	1,423	$	2,259	$	3,201	$	2,532
TRUE	**Sum debt service**		$	1,036	$	2,459	$	4,719	$	7,920	$	10,452
Total cashflow	$	(13,459)	$	536	$	1,423	$	2,259	$	3,201	$	2,532
IRR				16%								
	40%		$	(1,369)	$	(1,375)	$	(1,356)	$	(1,309)	$	(1,276)
	Base case		$	1,378	$	1,767	$	2,598	$	3,528	$	2,851
TRUE	**Sum debt service**		$	1,378	$	3,145	$	5,744	$	9,272	$	12,123
Total cashflow	$	(16,150)	$	878.19	$	1,767.04	$	2,598.32	$	3,528.47	$	2,851.18
IRR				15%								

Figure 7.7: The cash flow model for a low price ballast water treatment system including a loan.

The second row shows the yearly cash flow for the base case with debt service. The LIBOR and the NIBC margin creates the debt service. This is the total interest amount that has to be paid by the ship owner. The second row shows the sum of the total cash flow with debt service until the end of that specific year. When the sum of total cash flow with debt service is equal or larger than 0, the owner has enough liquidity to pay its debt service. This implies that when the owner has a positive total cash flow, it is assumed that this is used for a possible cash out until the final repayment date. When the total cash flow with debt service is positive every year, the loan is feasible. The highest debt service that can be paid with the cash flow of the vessel is also the highest LVT that can be acquired without having any negative cash flow as an owner.

A cash reserve option is also build in. This is a cash reserve that the owner keeps available to cover the cash-out when facing a bad market. When a cash reserve is given, this is added to the total cash flow as a cash-in, in the first year. At the same time, this cash reserve is added to the initial investment as it needs to be set apart. The cash flow reserve is set at \$ 500.000 as it represents the reality where the bank asks for a minimum liquidity for these situations.
When the debt service can be paid every year up until the latest repayment date, a new IRR can be calculated. The IRR is then based on the hypothetical initial investment of the owner. This is the current vessel value minus the loan amount as shown in equation plus the cash reserve 7.7.

$$Initial\,investment = (1 - LTV) * (Vessel\,value) + Cash\,reserve \tag{7.7}$$

When the rate of return of the vessel is higher than the interest of the loan, the IRR will be higher with a loan than without. The new rate of return is then calculated for the *Install a BWT system* scenario as shown in figure 7.8.

Low-end IRR with loan	Overview feasible loans	High-end IRR with loan	Overview feasible loans	No BWT IRR with loan	Overview feasible loans
0.0%	0%	0.0%	0%	0%	0%
0.0%	0%	0.0%	0%	0%	0%
19.8%	80%	19.8%	80%	23%	80%
17.5%	70%	17.5%	70%	20%	70%
15.9%	60%	15.9%	60%	18%	60%
14.8%	50%	14.8%	50%	16%	50%
13.9%	40%	13.9%	40%	15%	40%
13.1%	30%	13.1%	30%	15%	30%
12.5%	20%	12.5%	20%	14%	20%
12.0%	10%	12.0%	10%	13%	10%

Figure 7.8: Feasible loan to value with the new corresponding IRR

The maximum LTV with its corresponding IRR is then shown in the output table as discussed in section 7.9.

7.9. Output

The final vessel-specific output of the model consist of three tables and a graphical overview in which the expected IRR's and the differences are shown. The first table shows the vessel specifications which are used by the tool to come up with the output. This table is shown in figure reffig:vesselspecs. When the ballast water pump capacity is unknown. This is calculated with the vessel-type and DWT as explained in section 2.1.2.
FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS
The combination of the graphical overview and the table show the expected IRR's in different points in time. This overview is shown in figure **??**. Later in this section, the overview will be highlighted and discussed.
FIGURE REMOVED DUE TO CONFIDENTIALITY REASONS
The graphical overview in figure 7.9 shows the IRR that is expected to be realised at the end of each different scenario. When multiple strategies and scenarios end on the same date, the strategy with the highest IRR is shown.

- The light green column shows the best strategy in the scenario where a low-price ballast water treatment system is installed.
- The dark green column shows the best strategy in the scenario where a high-price ballast water treatment system is installed.
- The red columns show the scenarios in which the vessel is either sold or scrapped and no big investment is needed.
- The grey column shown the hypothetical scenario in which no ballast water treatment is installed. This is not a feasible scenario but is used as a reference.

The output is generated with the assumption that the total lifetime of all vessels is 20 years. This implies that the:

- Install a BWT system scenario (high-price and low-price)
- Hypothetical no BWT installation scenario

all end at the age of 20.
Each column also shows an error bar. Where the column itself shows the base case, the error bar shows the pessimistic and optimistic case. The pessimistic and optimistic cases are based on a 10% increase and decrease of the time charter rates of the vessel.

	2017	2018	2019	2020	2021	2022
IRR Pessimistic low price						
IRR Base case low price						
IRR Optimistic low price						
Investment needed						
IRR Pessimistic high price						
IRR Base case high price						
IRR Optimistic high price						
Investment needed						
Strategy						
IRR Sell / Scrap			1.17%			1.24%
IRR Sell / Scrap			2.23%			9.00%
IRR Sell / Scrap			1.19%			1.26%
Investment needed						-$ 6,311
Strategy Sell / Scrap			21			16
No BWTS Pessimistic						
No BWTS Base case						
No BWTS Optimistic						

Figure 7.9: Table underneath the graphical overview.

The exact numbers are shown in the table below the graphical overview **??**. The numbers that are shown in the graphical overview have the same color in the table. Figure 7.9 shows part of this table. In this example it can be seen that there are two strategies in which the ship owner can decide to either sell or scrap the vessel. The IRR for the base case is shown as the exact number. Below and on top of this number the increase and decrease of the IRR are shown. The strategy number and the required investment can also be found below. From this example it can be seen that with an investment of around $ 6.500,- [**?**], which is the price of an IOPP renewal, an increase in IRR of almost 7% can be realised with the extension of three years. The investment for an IOPP renewal is considered as something every ship owner can afford. This is why the highest IRR from the sell or scrap strategy is selected disregarding the small investment that has to be made in some cases.
The third table is shown in figure 7.10. This table shows all the output in a compact way. The first column shows the different cases for the three scenarios, just as shown in the graphical overview:

- Sell / Scrap (Pessimistic / Base-case / Optimistic)
- Install a BWT system (Low-price / high-price) (Pessimistic / Base-case / Optimistic)
- Hypothetical no BWT installed (Pessimistic / Base-case / Optimistic)

The second column shows the highest expected IRR for each specific case for every scenario.
The third column shows the Δ No BWT. This is the difference between the highest expected IRR and the IRR of the hypothetical scenario of not installing a ballast water treatment system. This shows the actual impact of the ballast water management convention on the ship owner. It is expected that the Δ No BWT is negative because the ballast water treatment investment will decrease the IRR. In some situations this is not the case. In a sell/scrap scenario, the cash flow model ends premature and the IRR can be higher than the IRR with no BWT installed. This can happen when vessel prices and time charter rates are expected to go down. It can also happen that the Δ No BWT is 0. This is the case when the vessel is at the end of its lifetime and no ballast water treatment system has to be installed. This is dependent on the vessels' age and the anniversary date. This indeed will mean that the impact is 0.

BWT Impact	IRR	Δ No BWT	Investment needed	Strategy	Δ low price system	Δ high price system	Maximum LTV	Maximum IRR	Δ No BWT
IRR Sell/Scrap Pessimistic	7,76%	-0,71%			0,39%	-0,01%			
IRR Sell/Scrap Base case	9,00%	-1,08%	$ 6.311	16	0,77%	0,37%			
IRR Sell/Scrap Optimistic	10,26%	-1,40%			1,08%	0,68%			
IRR low-price Pessimistic	8,15%	-0,32%							
IRR low-price Base case	9,77%	-0,32%	$ 395.865	17			50,00%	10,06%	-2,12%
IRR low-price Optimistic	11,34%	-0,32%							
IRR high-price Pessimistic	7,75%	-0,72%							
IRR high-price Base case	9,37%	-0,72%	$ 917.357	17			50,00%	9,57%	-2,61%
IRR high-price Optimistic	10,94%	-0,72%							
IRR No BWT Pessimistic	8,47%	0,00%							
IRR No BWT Base case	10,08%	0,00%	-	-			50,00%	12,18%	
IRR No BWT Optimistic	11,66%	0,00%							

Figure 7.10: Table with all IRR's and the impact on the IRR for different strategies.

The fourth column shows the investment that is needed to pursue the specific scenario. For the sell/scrap scenarios this can include the IOPP renewal cost. For the low-price and high-price solutions this can include the following costs depending on the strategy that is followed:

- IOPP renewal
- Preparation for installing a ballast water treatment system
- Finalizing the installation and the purchase of the ballast water treatment system
- Full installation and purchase of the ballast water treatment system

The costs shown in the fourth column are the strategy-specific discounted investment costs. The calculation and the discount rate will be explained in section 7.4.
The fifth column shows the strategy number that is used to attain the specific IRR. The hypothetical scenario does not show a strategy number as it is hypothetical and can not be considered as a strategy.
The sixth and the seventh column Δ low-price and Δ high-price show the difference between the sell/scrap scenario and the installation of a low-price and high-price system. This number shows the possible gain in IRR for the shipowner when an investment is made to either install a low-price or a high-price ballast water treatment system. When this number shows a negative value, this means that there is no possible gain in sailing the vessel with this ballast water treatment system. This implies that the vessel should be sold or scrapped.
The eighth column, Maximum LTV, shows the maximum debt service that the owner can pay for with the forecasted cash flows. The LTV is the loan to value. The LTV is the loan amount divided by the vessel value. The maximum LTV is the maximum loan that the owner can pay without any yearly cash-out.
The ninth column shows the maximum IRR that could be realised with the maximum loan to value.
The tenth column shows the Δ No BWT which is the difference in IRR with a bank loan compared to the fictional scenario where no ballast water treatment system is installed.

7.9.1. Other output

Besides the main output of the tool, more information can be retrieved. This section shows the other output of the tool.

- Next to the output of the IRR's which show the potential return, a table shows all of the different strategies. The strategies in blue show the possible economic best solutions. The red strategies will never become an ideal solution with the assumption that the price of the ballast water treatment systems remains constant as discussed in chapter 6.

Strategy	Feasibility	Total required investment	RFR scrap	RFR No BWT	RFR BWT	Payback (years) Pessimistic case	Payback (years) Base Case	Payback (years) Optimistic case
1								
2	TRUE	$ (465,147)		$ 7.18	$ 7.26	11	10	10
2	TRUE	$ (1,123,215)		$ 7.18	$ 7.36	11	11	10
3	TRUE	$ (465,147)		$ 7.18	$ 7.26	11	10	10
3	TRUE	$ (1,123,215)		$ 7.18	$ 7.36	11	11	10
4	FALSE	$ -	$ -			99	99	99
5	FALSE	$ -		$ -	$ -	99	99	99
5	FALSE	$ -		$ -	$ -	99	99	99
6	FALSE	$ -		$ -	$ -	99	99	99
6	FALSE	$ -		$ -	$ -	99	99	99
7								
8								
9								
10								
10								
11								
11								
12								
13	TRUE	$ (482,284)		$ 7.18	$ 7.26	11	10	10
13	TRUE	$ (1,174,499)		$ 7.18	$ 7.37	11	11	10
14	TRUE	$ (482,284)		$ 7.18	$ 7.26	11	10	10
14	TRUE	$ (1,174,499)		$ 7.18	$ 7.37	11	11	10
15								
16	TRUE	$ (6,500)	$ 5.59			6	6	6
17	TRUE	$ (471,646)		$ 7.18	$ 7.26	11	10	10
17	TRUE	$ (1,129,711)		$ 7.18	$ 7.36	11	11	10
18	TRUE	$ (471,646)		$ 7.18	$ 7.26	11	10	10
18	TRUE	$ (1,129,711)		$ 7.18	$ 7.36	11	11	10
19								
20								
21	TRUE	$ -	$ 4.10			3	3	3
22	TRUE	$ 465,147		$ 7.18	$ 7.26	11	10	10
22	TRUE	$ 1,123,215		$ 7.18	$ 7.36	11	11	10
23	TRUE	$ 465,147		$ 7.18	$ 7.26	11	10	10
23	TRUE	$ 1,123,215		$ 7.18	$ 7.36	11	11	10

Figure 7.11: Table with the output of the tool

The table shows the following content:

1. Strategy (every line resembles a strategy, in this column the strategy number is shown. Every strategy is shown twice, where the first is the installation of a low-price and the second a high-price ballast water treatment system)
2. Feasibility (shows whether or not the strategy is feasible to execute for this specific vessel)
3. Total investment cost (Shows the total nominal investment which is needed for this specific strategy, this number is also shown in the IRR output)
4. Payback (years) Pessimistic case (shows the payback time in years for the pessimistic case)
5. Payback (years) Base case (shows the payback time in years for the base case)
6. Payback (years) Optimistic case (shows the payback time in years for the optimistic case)

- With the previous output the most cost-efficient strategy for each scenario can be determined. This table overview is shown in figure 7.12.

Scenario	RFR	Percentile lower rates	Percentile higher rates	Δ RFR
Scrap	$ 4.10	0%	100%	
Current rate	$ 7.37	10%	90%	
20 year low price	$ 7.26	9%	91%	$ 0.08
20 year high price	$ 7.36	10%	90%	$ 0.19
20 year No BWT	$ 7.18	9%	91%	

Figure 7.12: Visualisation of the current market in which the vessel is in

The table shows the following content:

1. Scenario (Every line resembles a scenario, the rest of the data shows the economically ideal strategy for this scenario)

2. RFR (this shows the required freight rate for all scenarios. The RFR is given in (k$/day)
3. Percentile lower rates (this is the lower percentile of the required freight rate compared to the forecasts from 2016 to 2026. This means that this gives the percentage in which the rates are expected to be lower than the required freight rate)
4. Percentile higher rates (this is the higher percentile of the required freight rate compared to the forecast from 2016 to 2026. This means that this gives the percentage in which the rates are expected to be higher than the required freight rate)
5. ΔRFR (this is the difference in required freight rate of the specific scenario and the fictional scenario without a ballast water treatment system. This is the additional cost of the investment of a ballast water treatment system.)

These numbers are disclosed in a graphical overview shown in figure 7.13. In the chart, the RFR's and the current T/C rate are disclosed as vertical lines and an accumulated histogram in shown of the T/C rates for a given period of time (2016 to 2026). The intersection of the accumulated histogram with the RFR's shows the percentile of the rate. Next to that, the percentile of higher rates than required is displayed. This means that in X percentage of the cases, higher rates are expected, as shown in figure 7.12. As can be seen from the example, the difference in RFR for the low-price and high-price BWT system are relatively small.

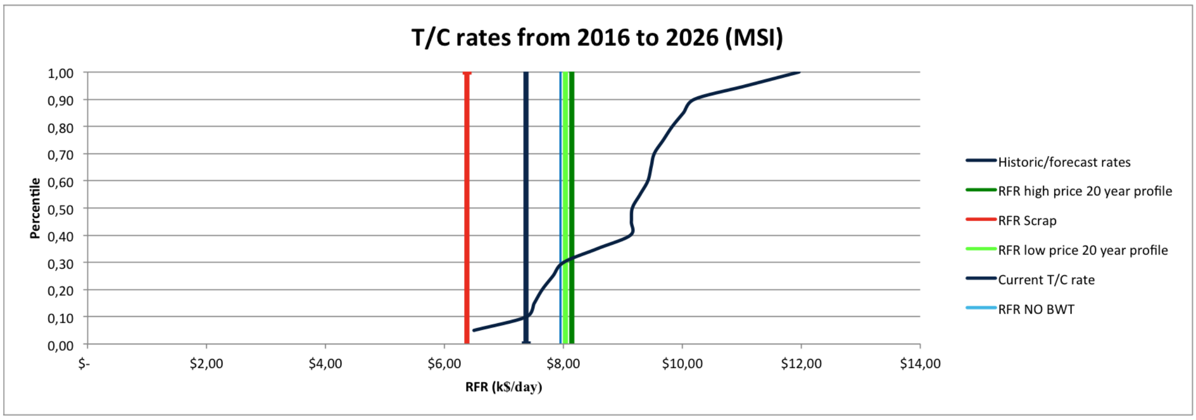


Figure 7.13: Visualisation of the output

The vertical lines in figure 7.13 show the calculated required rates.

- The red line shows the rate in which a sell/scrap scenario would be an option with a positive total cash flow.
- The vertical dark blue line shows the current T/C rate for this specific vessel.
- The light green and dark green vertical lines show the required freight rates.
- The dark blue line shows the accumulated histogram of the forecast rates.

• The last output is a table, shown in figure 7.14, with the pay-back profiles of the different scenarios.

Scenario	Years	Possible in 20 year profile?	Sailing profile
Pessimistic low price	11	TRUE	14
Pessimistic high price	11	TRUE	14
Base case low price	10	TRUE	13
Base case high price	11	TRUE	14
Optimistic low price	10	TRUE	13
Optimistic high price	10	TRUE	13
Sell/scrap	3	TRUE	6

Figure 7.14: Visualisation of the output

This table shows the following data:

1. Scenario (every line resembles the best strategy within the scenario, the rest of the data shows the economically ideal strategy for this scenario)
2. Years (pay-back time in years for the vessel and ballast water treatment investment(s))
3. Feasible 20 year pay-back time (whether it is possible to pay-back within the lifetime (20 years) of the vessel)
4. Sailing profile (this is the total sailing profile to pay-back for the ballast water treatment investment(s). This is the age of the vessel at the point it is paid-back)

8

NIBC portfolio and world fleet analysis: scenarios and strategies

This chapter is focussed on the ideal scenarios and strategies for the ship owner to follow. This is the output of the tool for both NIBC's portfolio and the world fleet.

8.1. Scenario analysis

The scenarios differ in whether to install a ballast water treatment system, either high-price or low-price, and the option to sell or scrap the vessel. The consideration of installing a ballast water treatment system is influenced by multiple factors:

- The IRR, based on forecasted rates, for the different scenarios
- The weighted average cost of capital
- The cash position of the owner

All three will now be briefly discussed together with the assumptions made for this report. In this report the highest expected IRR determines which scenario to follow.

8.1.1. The IRR, based on forecasted rates, for the different scenarios

The most obvious method for choosing a scenario is by comparing the expected IRR of the vessel for all scenarios. The scenario with the highest forecasted IRR would be the scenario to follow. This information can be easily acquired by the use of the tool. It has to be noticed that in some cases, the IRR can be higher for a sell or scrap scenario compared to a scenario where no ballast water treatment system was installed. This can be the case when an up-tick in value for this specific vessel is expected.

8.1.2. The weighted average cost of capital

"The cost of capital is simply the return expected by those who provide capital for the business." [**?**]. For shipowners, the cost of capital is commonly determined by the shareholders and a bank loan. The cost of capital of a bank loan is the total interest, which is the bank margin plus LIBOR. The shareholders also need a return on their investment. Together this is referred to as the weighted average cost of capital. When the expected IRR with a ballast water treatment system is lower than the weighted average cost of capital, the owner will not install a BWT system. In this case the IRR could not provide enough return to pay for the used capital. The weighted average cost of capital is assumed to be 9% based on the assumptions shown in table 8.1. A common ship finance facility provides 60% loan to value. The remaining 40% capital is to be provided by the shareholders. The total interest of the bank loan is assumed to be 5% whereas the shareholders expect a return of around 15%. This implies that when the IRR of the vessel drops below 9% due to the installation of a ballast water treatment system, the owner will try to renegotiate with the bank and shareholders. This can result in a scenario where the vessel has to be sold or scrapped. As for this report, it is assumed that the owner will follow the scenario with the highest forecasted IRR.

Capital origin	Percentage of total capital	Cost of capital
Bank loan	60%	5%
Share holders	40%	15%
Total	**100%**	**9%**

Table 8.1: Cost of capital assumptions

The weighted average cost of capital is used as a benchmark when analysing the impact for NIBC as a bank in chapter 10. Whenever the IRR drops below the weighted average cost of capital, the vessel is considered high risk because the forecasts show that the owner is not able to pay enough to the bank and/or shareholders. This will be discussed in more detail in chapter 10.

8.1.3. The cash position of the owner

The cash position of the owner is of importance because an investment is required for installing a ballast water treatment system. As discussed in chapter 5 prices for installation can range from $ 250,000,- up to $ 3,000,000.- when installation takes place in a European yard. When the cash position of the owner is not sufficient, a additional loan might be required. If no further funds can be borrowed and the cash position is not sufficient, the owner can be forced to sell or scrap the vessel. In this report it is assumed that the owner has a sufficient cash position to install a ballast water treatment system. This implies that the cash position has no influence in choosing a scenario. The cash position is of importance when determining the maximum loan to value. This will be discussed in chapter 10. The higher the possible loan to value, the lower the weighted average cost of capital can be. This is due to the fact that the loan can be higher against a lower interest rate compared to the interest paid to the shareholders. This will further be discussed in chapter 10.

8.2. NIBC fleet: Scenario analysis

For this report it is assumed that the owner has sufficient cash to install a ballast water treatment system. The scenario and strategy to follow is based on the highest possible IRR. Figure 8.1 shows which of the vessels from the NIBC fleet should sell or scrap and which should install a BWT system.

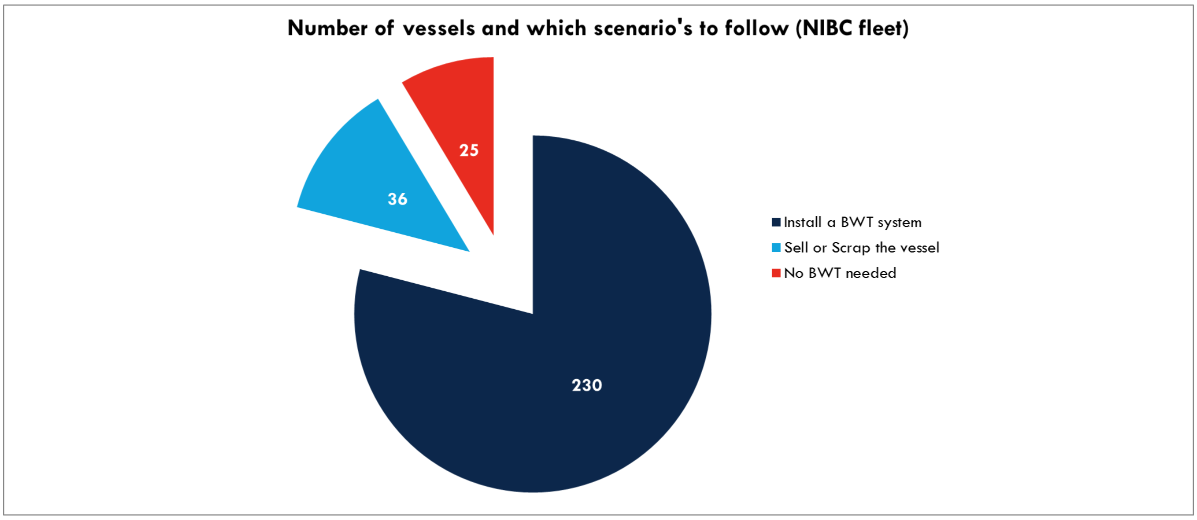


Figure 8.1: Overview of the ideal scenario to follow for the 291 NIBC fleet vessels.

Figure 8.1 shows that 79% of the portfolio should install a ballast water treatment system. 12% of the vessels should be sold or scrapped and 9% of the vessels do not have to install a BWT system at all. Only one vessel of the 12% sell or scrap scenario should be sold, which represents 0.3%. In chapter 8.4, these scenarios will be discussed together will the strategy that should be followed. This will give an explanation of the three different scenarios to follow as shown in figure 8.1.

When all the vessels follow the advice of the tool, 21 % of the vessels will exit NIBC's portfolio in five years time. This is due to vessels that are being scrapped or sold and the vessels reaching an age of 20 years. The impact this may have on NIBC will be discussed in chapter 10.

8.3. World fleet: Scenario comparison

To see how NIBC's portfolio is performing compared to the world fleet, a world fleet analysis is done. A database is created with the world fleet for the same vessel types as in NIBC's portfolio. All the vessels that are in idle or not operating anymore are excluded. Only vessels with a gross tonnage of 400 or above are taken into account. This resulted in a database with 21,930 vessels. The world fleet analysis is used as a benchmark to analyse the position of NIBC's portfolio within the world fleet.

Figure 8.2 shows the scenario to follow as a percentage of the world fleet. The percentage of the fleet that has to be sold or scrapped is the same while for NIBC's portfolio more vessels should install a BWT system. This implies that NIBC's portfolio contains younger vessels compared to the world fleet, which is the case. Furthermore, the percentage of vessels that should be scrapped is 0.5% for the world fleet against 0.3% of NIBC's portfolio. This implies that NIBC's portfolio is performing better compared to the world fleet.

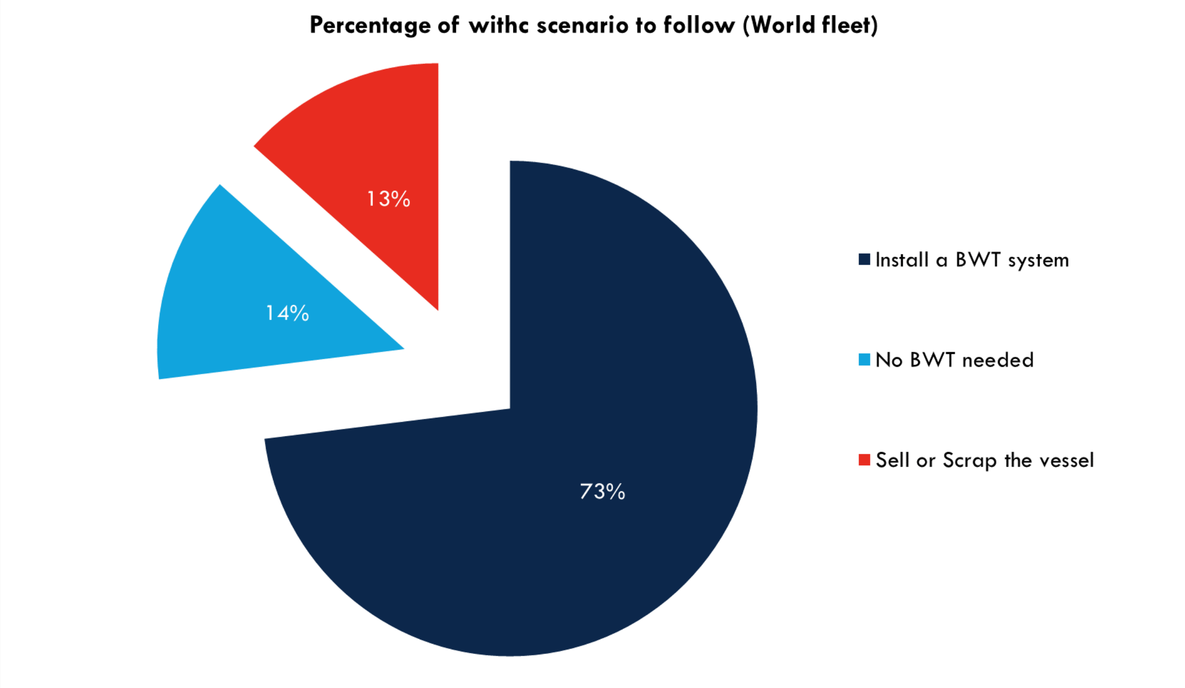


Figure 8.2: Overview of the ideal scenario to follow for the 21.930 vessels of the world fleet.

8.4. Strategy analysis

This section will be about the analysis of the NIBC portfolio with the use of the tool. The tool determines the ideal strategy based on the internal rate of return. For the fleet analysis this is done for every single vessel in NIBC's portfolio. A database is created with specific data for each vessel. This database shows the potential IRR and the difference in IRR with the hypothetical scenario where no BWT system has to be installed. This difference represents the impact of the IMO ballast water management convention measured in IRR. This section will discuss the different strategies that contributed to the highest IRR for each individual vessel. The strategies are grouped in scenarios as discussed in chapter 6. The different scenarios with the corresponding strategies based on the fleet analysis are shown in table 8.2. The summary of all strategies will be repeated briefly in this section. For a more detailed explanation on the strategy and the potential gain and/or loss can be found in chapter 6. In section 8 the choice for the different scenarios are discussed. This section will discuss which strategy to follow for each individual scenario.

Scenario	Strategies
Install a BWT system	2, 5, 17
No BWT system is needed	4, 16, 21
Sell or Scrap	4, 16, 21
Use alternative BWT method	No strategies, not considered for this research
Install No BWT system	*Hypothetical*

Table 8.2: Different scenarios with short description

8.4.1. Sell or scrap scenario (Strategies: 4, 16 and 21)

For the sell or scrap scenario there are three feasible strategies to implement according to chapter 6, this is either strategy 4, 16 or 21. The fleet analysis shows which of the three strategies is the ideal solution for each specific vessel, this is shown in figure 8.3. Table 8.3 shows a brief overview on the differences between the three strategies in the sell and scrap scenario.

Strategy	Explanation
4	Sell or scrap the vessel before the second dry-docking (first planned dry-dock before 8th of September 2017)
16	IOPP renewal, perform a regular dry-docking and sell or scrap the vessel before next IOPP renewal
21	Sell or scrap the vessel before first dry-docking (first planned dry-dock after 8th of September 2017)

Table 8.3: Overview of the three different strategies for the sell or scrap scenario.

The fleet analysis based on the output of the tool counts the number of vessels that should follow either strategy 4, 16 or 21 as shown in Figure 8.3.

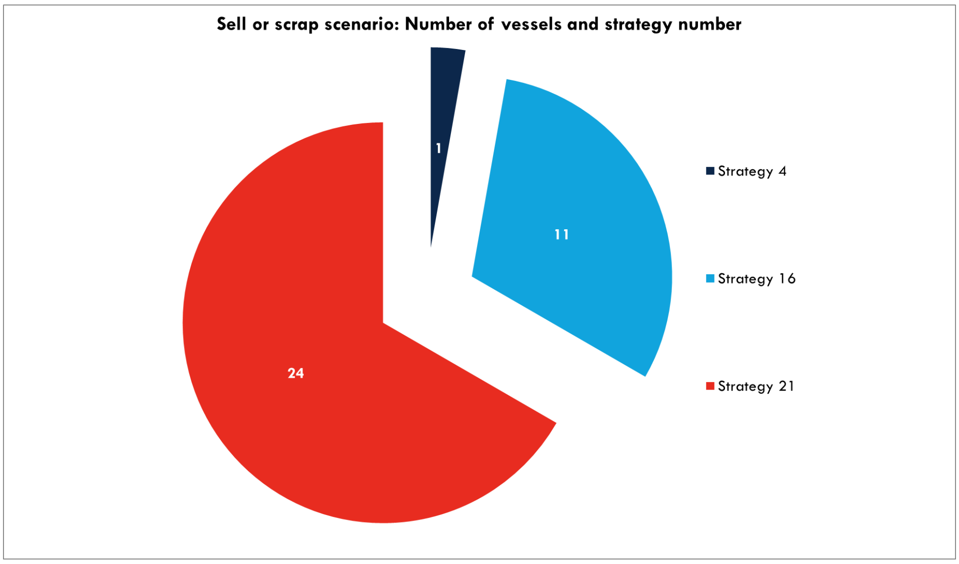


Figure 8.3: Overview of the ideal strategies for the 36 vessels that should follow the sell or scrap scenario.

Strategy 21

Figure 8.3 shows that more than half of NIBC's fleet would sell or scrap the vessel before the next dry-dock which is planned after the 8th of September 2017. This group of vessels will not see any benefit from performing an IOPP renewal and thus lengthening their BWT implementation schedule. This seems odd as the IOPP renewal is a very low cost option for extending the operation without having to have a ballast water treatment system. When looking at the number of vessels following strategy 21 which are able to perform early IOPP renewal, the reason can be found. The IOPP renewal is assumed to be an investment of only $ 6,500,- which

can almost be neglected when looking at the yearly T/C rates of at least a few million dollars. This raises the question on where the benefit from early selling or scrapping comes from.
First an overview of this group of vessels, which perform strategy 21 is split in two. The first group of vessels are able to perform an early IOPP renewal, these are indicated with *"True"*. The second group of vessels are not able to perform an early IOPP renewal and are thus forced to follow strategy 21. These vessels are indicated with *"False"*. This overview is shown in figure 8.4.

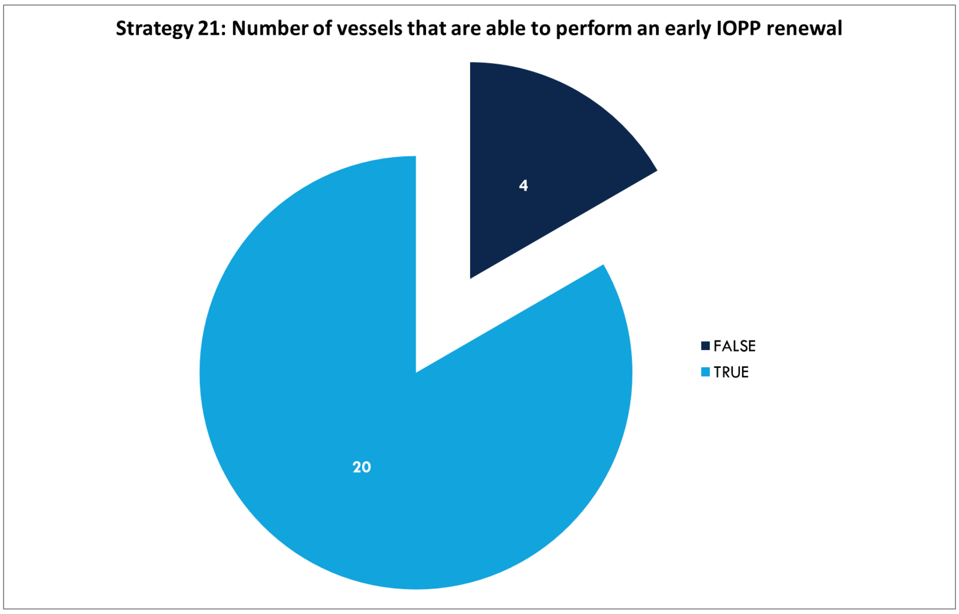


Figure 8.4: Overview of the 24 vessels that perform strategy 21 in a sell or scrap scenario. Whether or not they could perform an early IOPP renewal.

From figure 8.4 it can be seen that 4 of the vessels have no choice but to sell or scrap at the next planned dry-dock. For the other vessels there should be another reason.
When looking back at the cash flow models for strategy 21 for these specific vessels, it can be seen that MSI [**?**] forecasts a quick up-tick in vessel prices. This would imply that the market for this specific vessel is getting better. This would also imply that the freight rates would go up, as the demand for these vessels becomes bigger. This is verified by the MSI [**?**] forecasts on T/C rates. The up-tick in vessel value has instinctively a larger impact on a short time term, compared to the impact of the T/C rates. This means that these owners would be better off selling their vessels instead of sailing as long as they can.

The assumption is that the vessel is seen as an investment today, for today's vessel value. When the owner bought the vessel years ago for a higher price, it could well be that the owner chooses to sail on with the vessel. These cases thus have to be looked at very carefully when looking at one specific vessel.

Figure 8.5 shows how the up-tick in vessel price can create an opportunity for the owner to sell the vessel with the highest IRR. The figure shows the vessel value at every moment in time and the net earnings. The IRR is calculated for every year. Because of the up-tick in vessel prices, the IRR will be the highest when selling the vessel in 2018. This is exactly what happens with some the vessels that follow strategy 21. As mentioned before, it can well be that the owner bought the vessel for a higher price than the current vessel value. This can imply that the owner does not want to sell the vessel but wants to keep sailing.

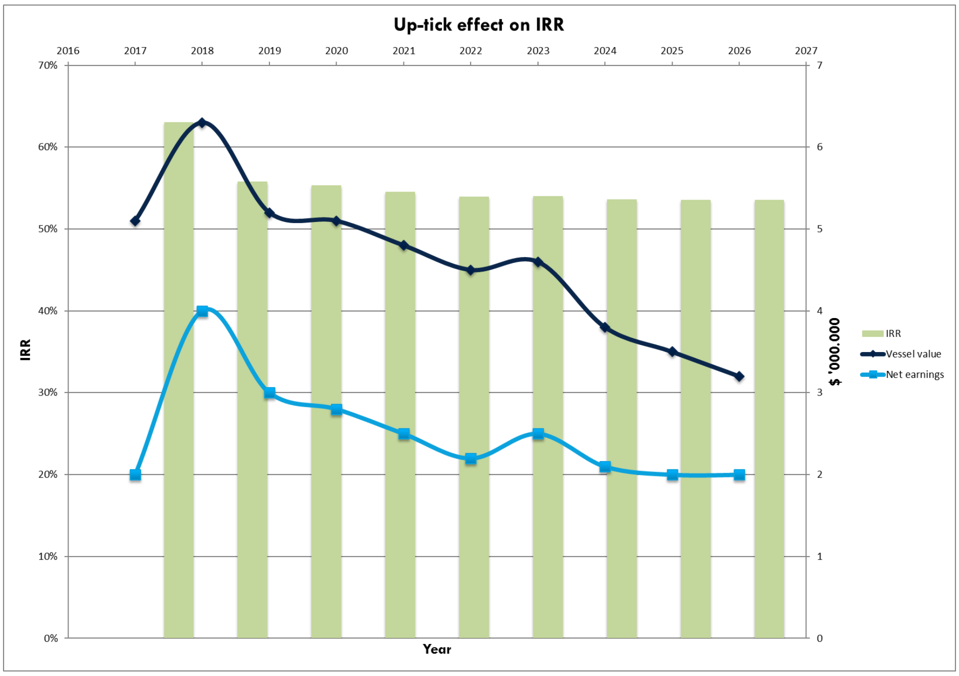


Figure 8.5: The effect on IRR of an up-tick in vessel prices.

What can be concluded from the fleet analysis is that strategy 21 can have two main causes to be the ideal strategy.

- The vessel is not able to perform an IOPP renewal before the 8th of September 2017.
- An up-tick in the market for this specific vessel is forecasted which causes the quick sell of a vessel to be the best strategy.

For 11% of NIBC's portfolio, the up-tick in vessel price causes strategy 21 to be the most ideal. Only 1% of the vessels should be scrapped caused by the need for a ballast water treatment system.

Strategy 4 and 16
Strategy 4 and 16 both try to postpone the need for installation of a BWT system to continue the operation before selling or scrapping the vessel. From figure 8.3 it can be seen that only a very small group of vessels is advised to perform strategy 4. The choice for strategy 4 or 16 is made very easily. Strategy 4 will have the same postponement as with strategy 16, both 5 years. Strategy 4 does not have to pay for an early IOPP renewal while strategy 16 does.

What can be concluded from this fleet analysis is that strategy 4 will be chosen as an ideal solution when possible. The ship owner has to have the convenience that the vessels' anniversary date is less than three months after the 8th of September 2017. When this is the case, the owner can lengthen the operation of the vessel without any investment.

Analysis on sell or scrap scenario strategies
What can be concluded from the fleet analysis is that the choice between the three strategies for the sell or scrap scenario can be divided in a few steps:

1. When MSI [**?**] forecasts an up-tick in vessel value on a short term, the owner of the vessel should follow strategy 21.
2. When the vessel is not able to renew its IOPP in time, the owner of the vessel is forced to follow strategy 21.
3. When the vessel is able to perform an early IOPP renewal, the owner of the vessel should follow strategy 4 or 16.

4. When the vessel can perform a regular dry-docking just before the going into-force date of the ballast water treatment convention, the ship owner should follow strategy 4.

5. When the vessel can perform an early IOPP renewal the owner should follow strategy 16.

8.4.2. No BWT system needed scenario (Strategies 4, 16 and 21)

The first thing that can be seen from figure 8.1 in chapter 8 is the fact that not all vessels have to install a ballast water treatment system. In total, 25 vessels do not have to install a system at all. This is driven by the assumption that the lifetime of a vessel is 20 years. This means that some vessels, with or without postponing, could sail for a total of 20 years without installing a ballast water treatment system. As can be seen from figure 8.6 most of the vessels do not have to undertake any additional measures to make sure no ballast water treatment system has to be installed before the age of 20. For both strategies 21 and 4, the owner has to do nothing but to perform the regular special survey for strategy 4. For strategy 16, which requires an early IOPP renewal, the owner has to make the small investment to let the vessel operate until the age of 20.

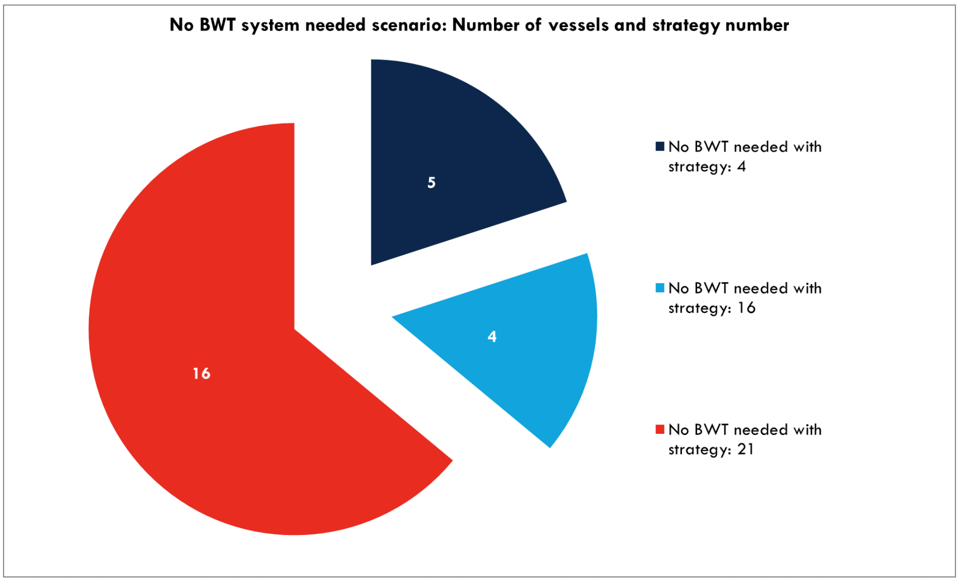


Figure 8.6: Overview of the ideal strategies used for the 25 vessels that do not need to install a BWT system.

8.4.3. Install a BWT system, low-price or high-price (Strategies 2, 5 and 17)

For the BWT installation scenarios, low-price or high-price, there are three feasible strategies to implement according to chapter 6. The fleet analysis shows which of the three strategies is the ideal solution for each specific vessel, this is shown in figure 8.7. Table 8.4 shows a brief overview on the differences between the three strategies in the BWT installation scenario.

Strategy	Explanation
2	Installation of a BWT system at the first dry-docking, when the first dry-dock is planned after 8th of September 2017
5	Installation of a BWT system at second dry-docking, when the first dry-dock is planned before the 8th of September 2017
17	Renew IOPP, perform regular dry-docking and install BWT before the second IOPP renewal

Table 8.4: Overview of the three different strategies for the sell or scrap scenario.

Strategies that need to install a BWT system

Most of the vessels from the NIBC fleet need to install a ballast water treatment system. For these vessels it is important to know which strategy to follow to gain the highest possible IRR. Figure 8.7 shows the number of vessels that need to install a BWT system and which strategy to follow.

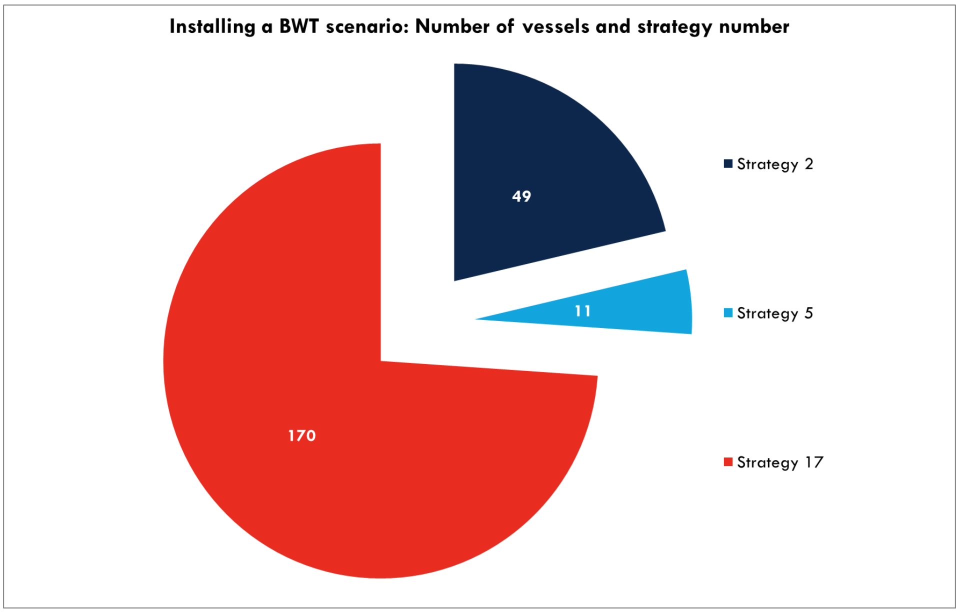


Figure 8.7: Overview of the ideal strategies used for the 230 vessels that need to install a BWT system.

Strategy 5 and 17
As can be seen from figure 8.7, strategy 17 is the best strategy for most of the vessels. The IOPP renewal extends the installation date which means an extension of the investment which has a positive impact on the IRR. Figure 8.7 only shows a small amount of vessels suitable for strategy 5. The choice for strategy 5 or 17 is made very easily. Strategy 5 will have the same extension as with strategy 17, both 5 years. Strategy 5 does not have to pay for an early IOPP renewal while strategy 16 does. When a vessel is able to plan its next survey just before the going into-force date of the ballast water management convention, the owner will chose strategy 5.

Strategy 2
Strategy 2 installs the BWT system during the first dry-docking after the 8th of September 2017. When looking into the vessels that should perform strategy 2, it is concluded that these vessels are forced to do so, as all vessels, except for one, can not renew the IOPP before the going into-force date of 8 September 2017. This exception is due to the fact that the vessel was built in March 2017. This means that the first special survey will be in 2022, which can not be extended with an IOPP renewal.

8.4.4. Analysis on BWT system installation scenarios

What the fleet analysis shows was that not all vessels have to install a ballast water treatment system without needing to prematurely sell or scrap the vessel. For 25 of the NIBC fleet vessels, no ballast water treatment system has to be installed. This is based on the 20 lifetime of 20 years of all vessels. When no installation of a ballast water treatment system is needed it means that no investment is needed, which has a positive effect on the IRR.
For the vessels that do install a ballast water treatment system the choice of strategy is also easily made. When the next survey is planned just before the 8th of September, the owner should go with strategy 5. When an IOPP renewal is possible but strategy 5 is not, strategy 17 should be followed. When an early renewal of the IOPP is not possible, the vessel is forced to follow strategy 2 which will install the system during the first planned dry-docking.

When summarizing this, a check list can be made for choosing the right strategy for the BWT system installation scenario:

1. When the vessel's next special survey is planned after the vessel's age of 20, the owner should follow strategy 2. The owner does not have to invest in a ballast water treatment system.

2. When the vessel its next special survey is planned before the 8th of September 2017 and the second

special survey is planned after the age of 20, the owner of the vessel should follow strategy 5. The owner does not have to invest in a ballast water treatment system.

3. When the vessel is able to renew the IOPP and the second IOPP renewal is planned after the vessel's age of 20, the owner should follow strategy 17. The owner does not have to invest in a ballast water treatment system.
4. When the vessel's next special survey is planned before the 8th of September 2017, the owner should follow strategy 5. This implies that the owner has to install a ballast water treatment system during the second special survey.
5. When the vessel's next special survey is planned after the 8th of September 2017 but the vessel is able to renew the IOPP, the owner should follow strategy 17. This implies that the owner has to install a ballast water treatment system during the second IOPP renewal.
6. When the vessel can not renew the IOPP, the owner is forced to follow strategy 2 and has to install the ballast water treatment system during the next survey.

9

NIBC's portfolio and world fleet analysis: impact of the ballast water treatment system on the IRR

This chapter is about the impact of the ballast water treatment system on the IRR of the vessel. The impact on the IRR is calculated for the installation of a BWT system scenario, high-price or low-price, and the sell or scrap scenario as described in section 7.4.3. The definition of the impact of the BWT installation scenario equals to Δ IRR, this can be calculated for the low-price and high-price BWT system and for all three cases: Pessimistic, Base case and Optimistic. The equation for the Δ IRR is shown in equation 9.1.

$$\Delta\, IRR = IRR\, No\, BWT - IRR\, BWT \tag{9.1}$$

In some cases, the owner has to sell or scrap the vessel. In this case, the impact of the ballast water treatment convention on the IRR is calculated with equation 9.2.

$$\Delta\, IRR = IRR\, No\, BWT - IRR\, Sell/Scrap\, scenario \tag{9.2}$$

As discussed in chapter 8 the choice of scenario is based on the highest forecasted IRR. Because the main goal of this research is showing the impact of the ballast water management convention the Δ IRR is calculated for the *"installing a BWT system"*, high-price and low-price, scenarios. This will be discussed in the next sections of this chapter for all vessel-types within the NIBC fleet.

9.1. Bulk Carriers

The NIBC fleet covers 91 bulk carriers which covers 31% of the number of vessels in the portfolio. These vessels, together with the product- and crude tankers, cover the largest part of NIBC's portfolio. This emphasises the fact that these vessels are important for the bank.

9.1.1. Δ IRR

Figure 9.1 shows the average Δ IRR, representing the absolute impact on IRR, for all bulk carriers in NIBC's portfolio for the installation of a BWT system. The horizontal axis shows the year in which the vessels are built and the vertical axis shows the average Δ IRR caused by the installation and operation of a ballast water treatment system.

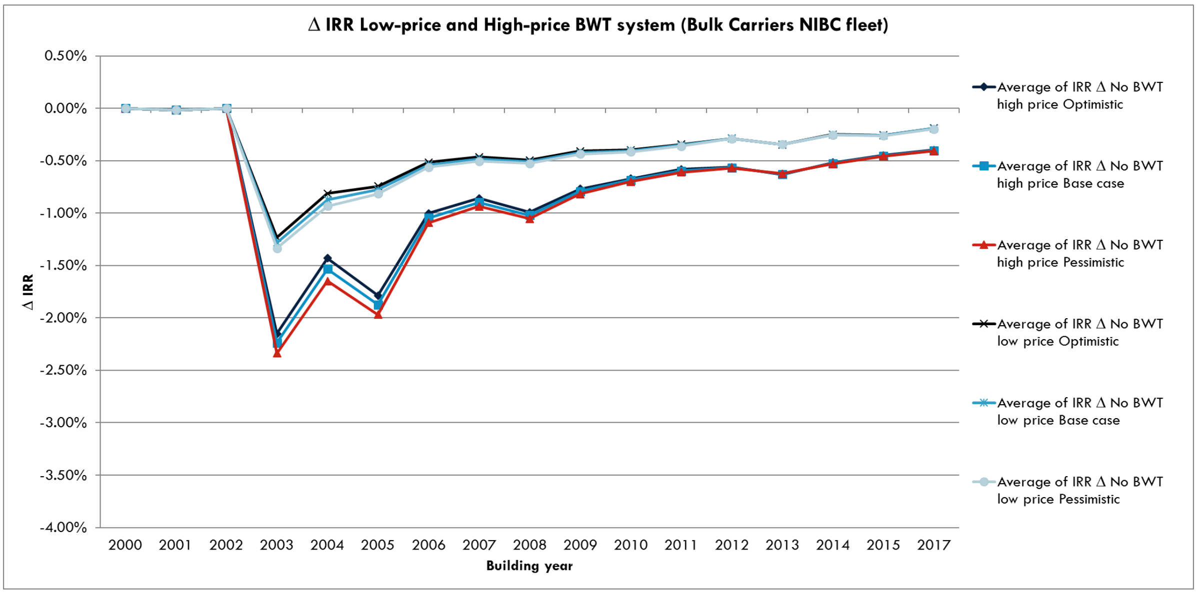


Figure 9.1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of Bulk carriers.

It can be seen from figure 9.1 that vessels up to 2002 are not impacted by the ballast water treatment convention. With the assumption that the lifetime of a vessel is 20 years, these vessels are able to follow a strategy whereby they reach the end of their economic lifetime without the need to install a BWT system. This implies that there is no difference in IRR.

For vessels build after 2002, one can conclude from figure 9.1 that the older the vessel is, the higher the impact of the ballast water treatment system will be. This is sensible to explain due to the fact that older vessels have less time to make up for the investment of a BWT system. The figure shows that the impact of a ballast water treatment system, high-price and low-price, can vary around -2.3% and -1.3% for a 2003 built vessel. For a vessel built in 2017 the impact can vary around -0.4% and -0.2%. Furthermore an almost exponential correlation between the building year and the impact in IRR can be found.

Figure 9.1 also shows some extreme values for the impact on IRR. These extremer cases can be explained by the fact that a vessel build in 2003 might have to install a BWT system in 2018, in case it did not renew its IOPP in time. This has a big impact on the IRR, due to the time value of money, as the investment has to be made in 2018 already. Furthermore the vessel is only able to sail for a maximum of six years after installation giving it little time to earn back the investment. This same effect can be seen in 2008 and 2013, vessels which were built one or two special surveys later. These vessels have exactly the same problem as these are the first vessels which have to install a ballast water treatment system. The extreme value for the impact of a high-price BWT system for the 2005 built vessels is caused by the fact these all these vessels have a ballast water pump capacity around 1,300 m3/h. For most vessels a BWT system with a capacity of 1,500 m3/h is needs to be installed because of the lack of systems with a smaller capacity. As can be seen from the cost analysis in chapter 5 the price range for ballast water treatment systems is the highest in this point.

It can be seen from figure 9.1 that the impact of the building year is getting smaller for the newer vessels. This can be explained by the fact that the vessels built in 2003 compared to the 2008 and 2013 built vessels have respectively 5 and 10 years more left to sail. This implies that the newer vessels have more time to earn back the investment of the ballast water treatment system.

Figure 9.2 shows the impact on IRR for the bulk carriers for the world fleet. It can be seen that the impact of the BWM convention for a 2003 bulk carrier is around -2.6 to -1.4%. The the impact shows less volatility for the world fleet because the impact is shown as an average of all vessels. Nevertheless, the impact is larger for the world fleet compared to NIBC's portfolio. Vessels build in 2005 from NIBC's portfolio suffer almost as much impact compared to the world fleet but overall NIBC performs better.

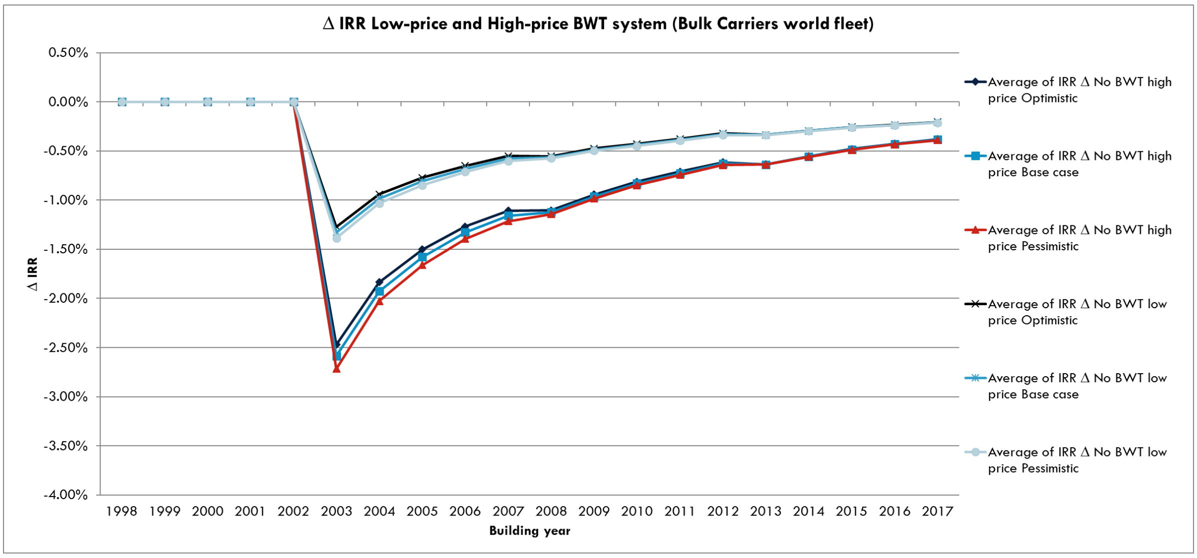


Figure 9.2: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of Bulk carriers.

9.1.2. IRR

The previous subsection showed the impact of the ballast water treatment system on the IRR of the bulk carriers from NIBC's portfolio. To put this in perspective, the actual IRR after the installation of a BWT system is calculated. In some cases the IRR drops below the cost of capital, which implies that the owner is not able to meet its minimum required return. The IRR that the vessels are able to get with the installation of a ballast water treatment system, when needed, is shown in figure 9.3.

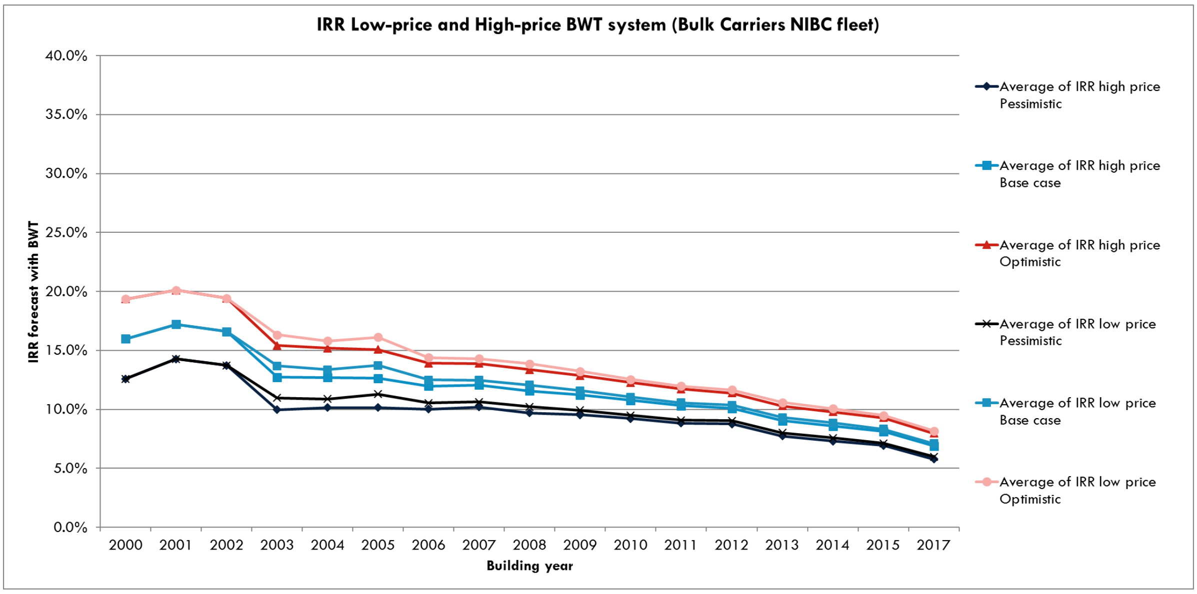


Figure 9.3: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of NIBC's portfolio of Bulk carriers.

Figure 9.3 shows, just as figure 9.1, that the vessels built until 2002 are not impacted by the ballast water management convention. This figure shows that the impact of the high-price BWT system compared to the low-price system is small until around the 10 year old vessels where after the difference is merely visible. It can also be seen that the impact of the installation of a ballast water treatment system can in no way be compared to the impact of a change in T/C rates. The assumed 5% increase and decrease for an optimistic and pessimistic case impacts the IRR of the bulk carriers way more than a ballast water treatment system does. This implies that actually the market forecasts in freight rates is a much more important factor compared to the implementation of the ballast water management convention.

Figure 9.4 shows the IRR forecasted with the installation of a BWT system when needed for the world fleet. When comparing this output with NIBC's portfolio it can be seen that NIBC performs a little bit better especially with the older vessels.

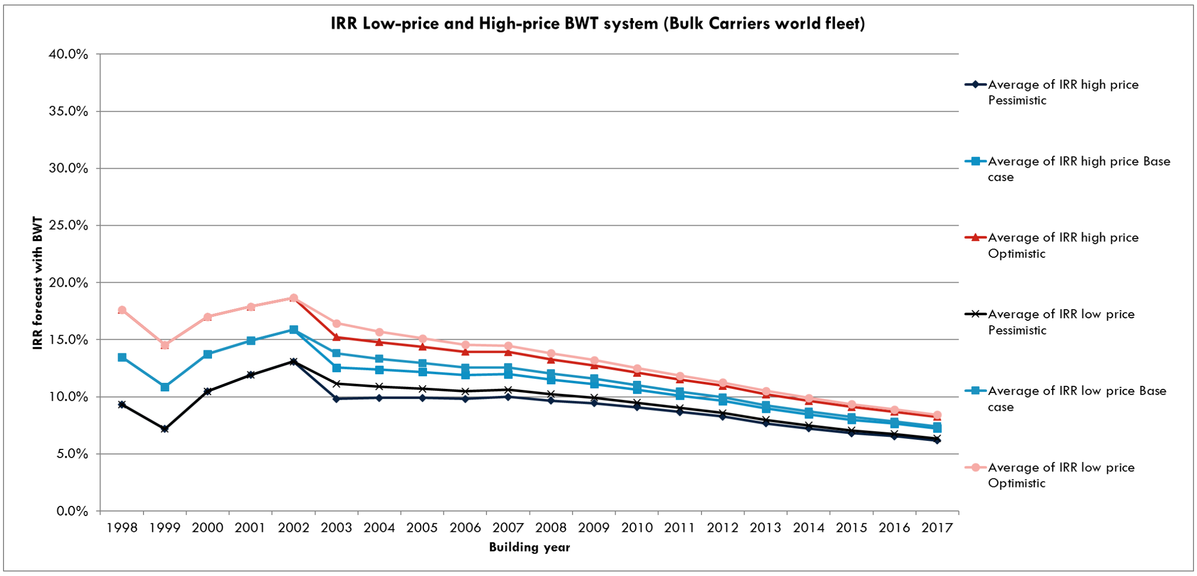


Figure 9.4: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the world fleet of Bulk carriers.

9.2. Product tankers

NIBC's portfolio covers 64 product tankers which is 22% of the number of vessels from the entire fleet. These vessels, together with the bulk carriers, cover the largest part of NIBC's portfolio.

9.2.1. Δ IRR

The product tankers are categorised by building year and the impact on the IRR is calculated for the low-price and high-price ballast water treatment installation scenarios. This is shown in figure 9.5.

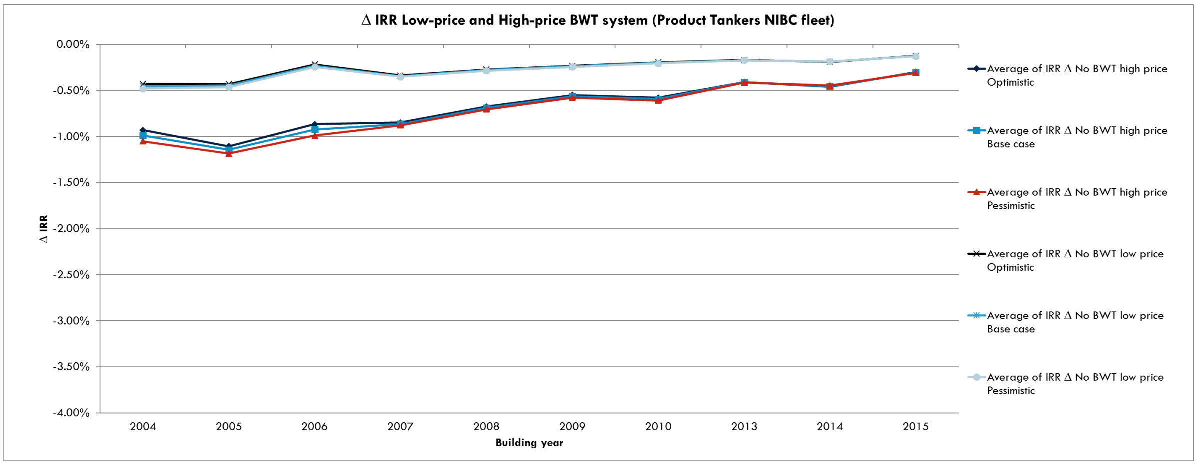


Figure 9.5: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of Product tankers.

It can be seen from figure 9.5 that all product tankers in NIBC's portfolio are impacted by the ballast water treatment convention.
From figure 9.5 one can conclude that, just as with the bulk carriers, the older the vessel is, the higher the impact of the ballast water treatment system will be.
Compared to the bulk carriers, the impact of the ballast water treatment system is much smaller. A vessel built in 2004 shows an impact between -1.0% and -0.4%. The youngest vessels in NIBC's fleet, built in 2015, only show an impact between -0.3% and -0.1%. Again in this case a clear linear correlation can be found between the year built and the impact of the ballast water treatment system on the IRR of the vessels.
Compared to the bulk carriers, these product tankers will be impacted almost half on the impact on IRR from the installation of a BWT system. The main reason for this is the current vessel values of both vessel-types. Bulk carriers are less expensive for the deadweight they can carry compared to the product tankers. Also the average BWT system for a product tankers is lower compared to a system for a bulk carrier. The impact of the investment of a BWT system is thus much smaller for a product tanker compared to a bulk carrier. This can all be seen in the overview created by the tool visualised in table 9.1.

vessel-type	Avg. pump capacity (m3/h)	Avg. BWT price	Avg. Vessel value
Bulk carrier	2039	$ 796,000	$ 13,530,000
Chemical tanker	553	$ 553,000	$ 17,403,000
Container carrier	975	$ 260,000	$ 9,426,000
Crude tanker	3825	$ 1,230,000	$ 25,785,000
LPG carrier	942	$ 665,000	$ 35,856,000
Product tanker	1510	$ 721,000	$ 17,905,000

Table 9.1: Overview of NIBC's portfolio per vessel-type with the corresponding average ballast water pump capacity, price and the vessel value in 2017

Furthermore in figure 9.5 it can be seen that the 2005 and 2007 built vessels face slightly more impact compared to the older vessels. The installation date for vessels built in 2005 and 2007 are planned around 2020 while most other vessels will install a BWT system in 2022.

Figure 9.6 shows the impact on IRR for the world fleet of product tankers. Again, NIBC's portfolio shows a little less impact compared to the world fleet. The two small dips for 2008 and 2013 built vessels can not be seen in NIBC's portfolio, meaning that NIBC's vessels will have an extra benefit compared to the world fleet. A vessel built in 2004 shows an impact between -1,3% and -0,5%.

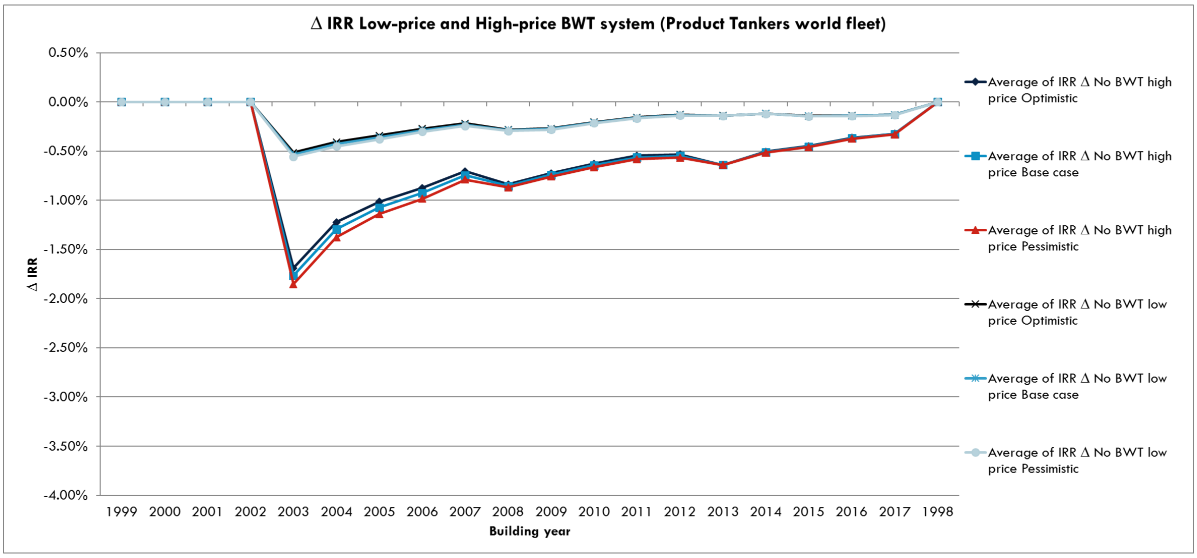


Figure 9.6: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of Product tankers.

9.2.2. IRR

The forecasted IRR's that the product tankers are able to get with the installation of a ballast water treatment system is shown in figure 9.7.

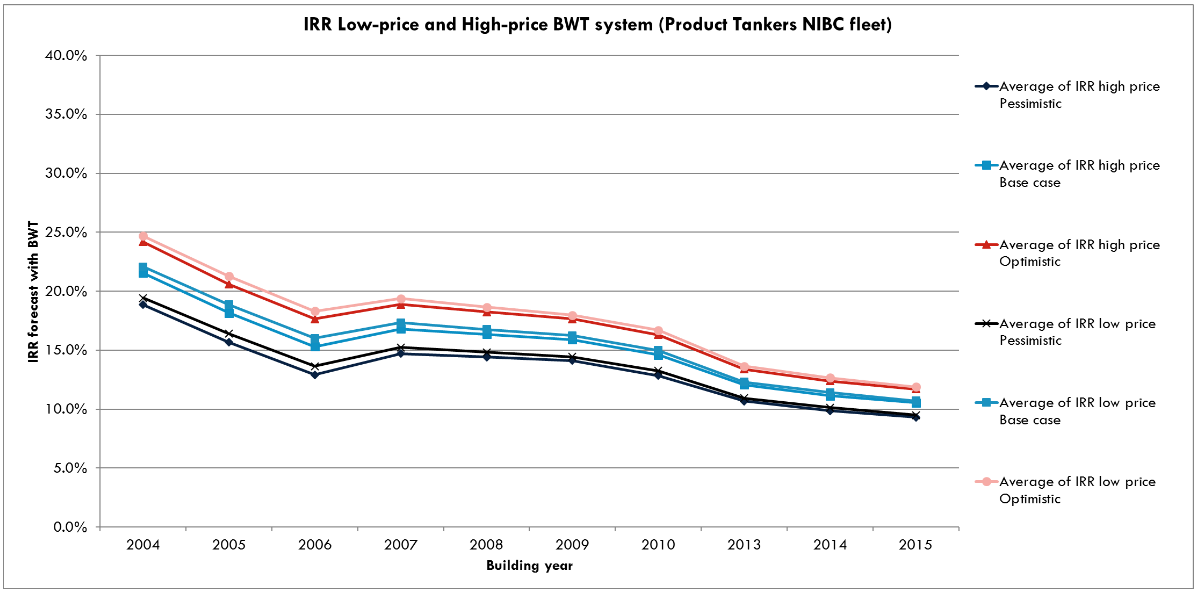


Figure 9.7: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of NIBC's portfolio of Product tankers.

Figure 9.7 again shows that the impact of the high-price BWT system compared to the low-price system is small compared to the different cases.
Just as for the bulk carriers, the installation of a BWT system show even less impact compared to the change in T/C rates which. This is explicable as the absolute impact shown in figure 9.5 shows less impact on IRR compared to the bulk carriers.
The forecast also shows that for the product tankers, the IRR with a high-price system in a pessimistic market will stay above 9.5% with a cost of capital of around 9% this shows a good prospect for all product tankers in NIBC's portfolio.

Figure 9.8 shows the IRR for the product tankers of the world fleet. Also for the product tankers the IRR turns out to be higher for NIBC's portfolio compared to the world fleet. Only the vessels built in 2006 in NIBC's portfolio perform less compared to the world fleet.

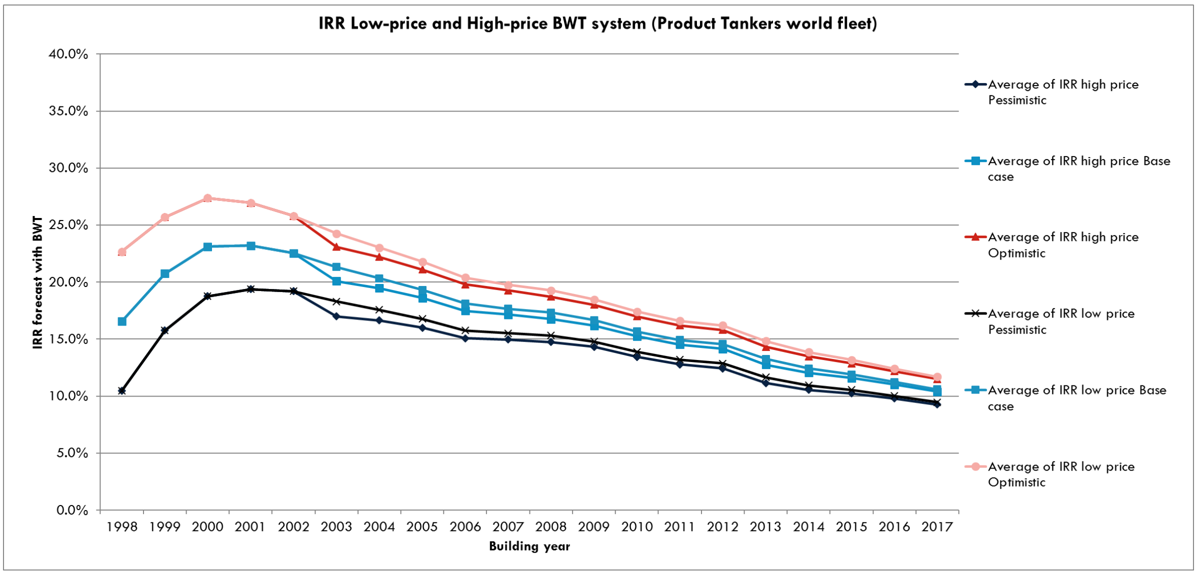


Figure 9.8: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the world fleet of Product tankers.

9.3. Chemical tankers

NIBC's portfolio covers 63 chemical tankers which is 22% of the number of vessels from the entire fleet. These vessels, together with the bulk carriers and product tankers, cover the largest part of NIBC's portfolio.

9.3.1. Δ IRR

The chemical tankers categorised by building year and the impact on the IRR is calculated for the low-price and high-price ballast water treatment systems is shown in figure 9.9.

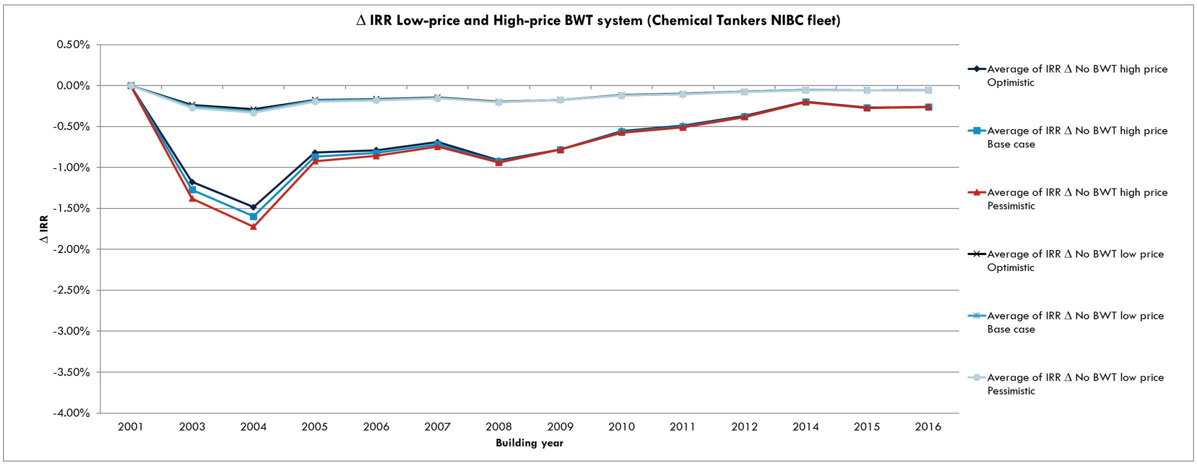


Figure 9.9: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of Chemical tankers.

It can be seen from figure 9.9 that almost all chemical tankers in NIBC's portfolio are impacted by the ballast water treatment convention.
A vessel built in 2003 shows an impact between -1,3% and -0,3%. The youngest vessels in the NIBC fleet, built in 2016, only show an impact between -0.2% and -0.1%.
Furthermore in figure 9.9 it can be seen that the 2004 built vessels face more impact compared to the vessels built in 2003. This can be lead back by the fact that the portfolio consist of 2 vessels that were built in 2004. These vessels are both smaller than the other vessels from the portfolio. Therefore the vessel value is relatively much lower compared to the other vessels. The ballast uptake for chemical tankers is much lower compared to tankers and bulk carriers. This implies that the impact of a ballast water treatment system, which does not differ that much in price, is much larger.

Figure 9.10 shows the impact on IRR for the chemical tankers of the world fleet. A vessel built in 2003 shows an impact between -1,3% and -0,5%. Again it can be seen that NIBC's portfolio is more volatile regarding the impact on IRR. Overall NIBC's portfolio show less impact compared to the world fleet. For the vessels built in 2003, 2005, 2006, 2007 and 2014, the impact for NIBC's portfolio is even much smaller.

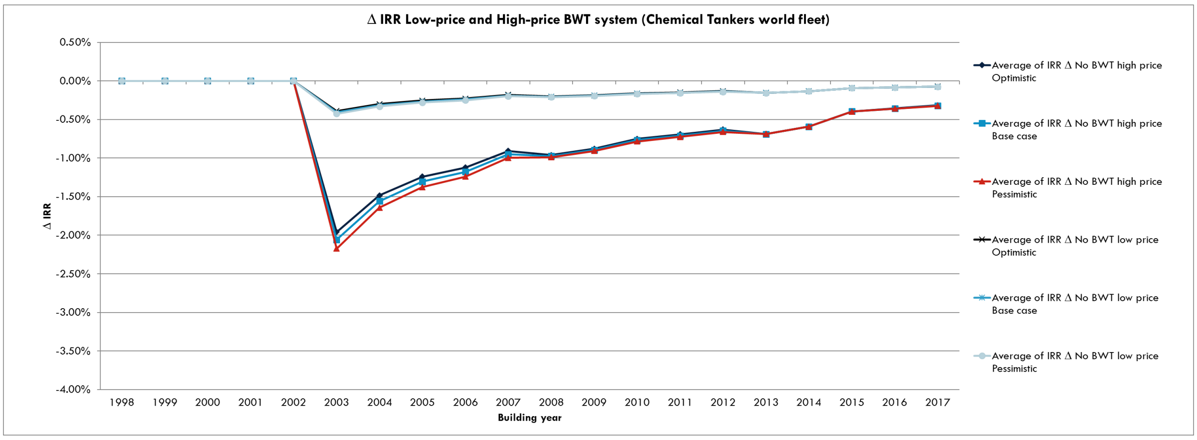


Figure 9.10: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of Chemical tankers.

9.3.2. IRR

The forecasted IRR's that the chemical tankers are able to get with the installation of a ballast water treatment system is shown in figure 9.11.

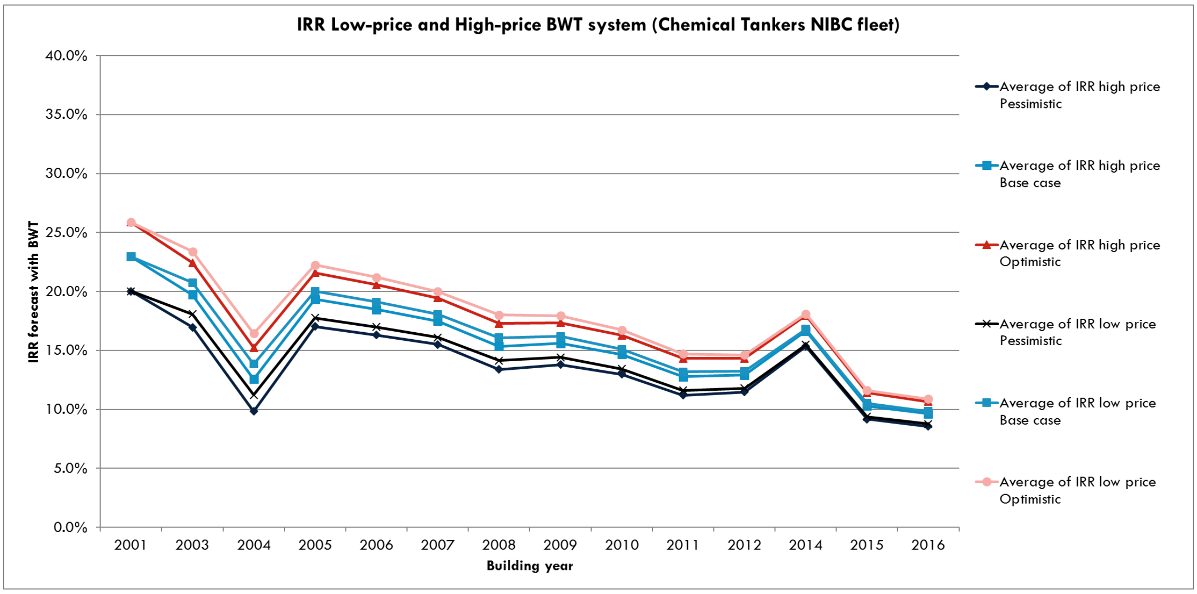


Figure 9.11: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of NIBC's portfolio of Chemical tankers.

The forecast shows that for the chemical tankers, the IRR with a high-price system in a pessimistic market will stay above 8.8% with a cost of capital of around 9% this shows a return which is just not enough. This can be solved by taking a larger bank loan or by reducing the return on own equity.

Figure 9.12 shows the average IRR of the world fleet of chemical tankers. Again more volatility can be seen for NIBC's portfolio. For the older vessels the world fleet is performing better compared to NIBC. For the vessels built in 2005 up until 2014, NIBC's portfolio is performing better. For the vessels built in 2015 and 2016, the world fleet performs slightly better than NIBC.

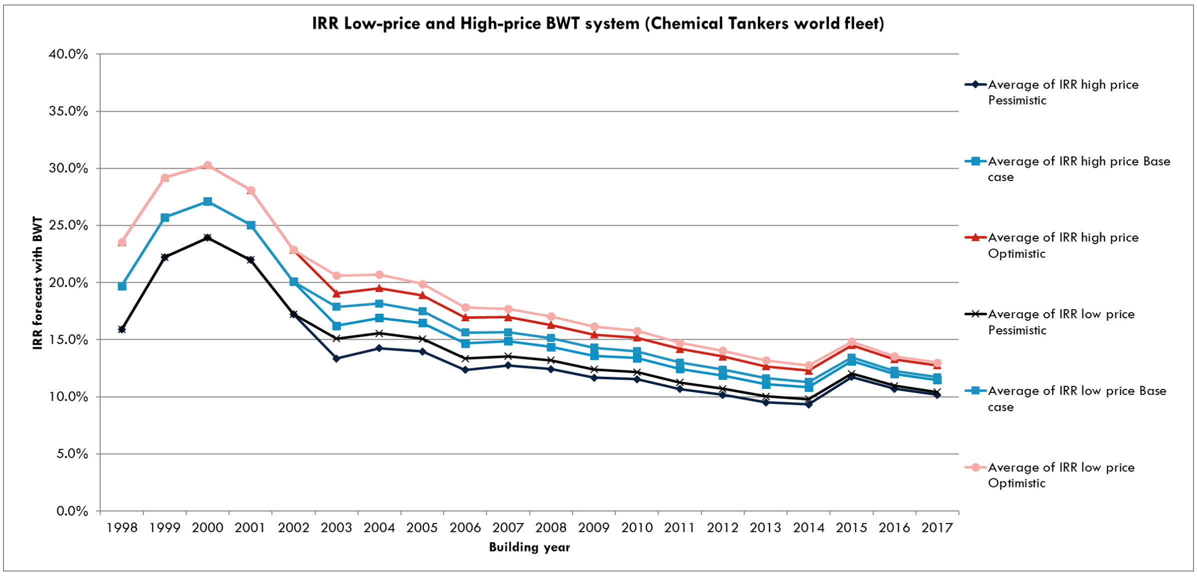


Figure 9.12: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the world fleet of Chemical tankers.

9.4. LPG carriers

The NIBC fleet covers 33 LPG carriers which covers around 11% of the entire fleet.

9.4.1. Δ IRR

The Δ IRR for the LPG carriers of NIBC's portfolio is shown in figure 9.13.

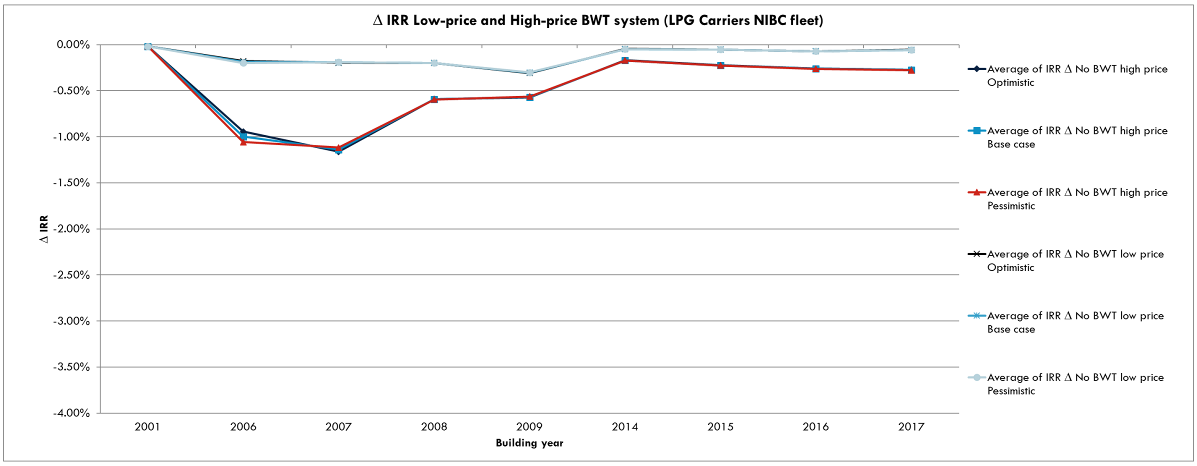


Figure 9.13: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of LPG carriers.

Figure 9.13 shows an impact on the IRR for the 2006 built vessels between -1.0% and -0.2%. A 2017 built vessel shows an impact between -0.2% and -0.1%. Again a linear correlation between the building year/age of the vessel and the Δ IRR can be found.
Vessels built in 2007 show a larger impact compared to the rest of the vessels. This can be traced back to the fact that half of the vessels which were built in 2007 have to have a BWT system installed in 2018.

Figure 9.14 shows the impact on IRR for the LPG carriers in the world fleet. It can be seen that overall, the world fleet is performing a little bit better compared to NIBC's portfolio. A vessel built in 2006 shows an impact between -0,7% and -0,2%.

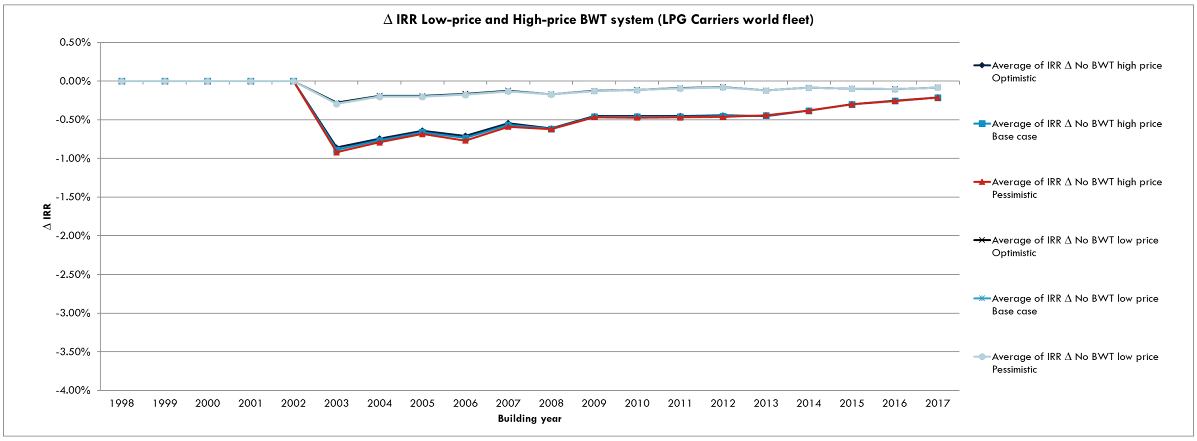


Figure 9.14: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of LPG carriers.

9.4.2. IRR

The forecasted IRR's that the LPG carriers are able to get with the installation of a ballast water treatment system is shown in figure 9.15.

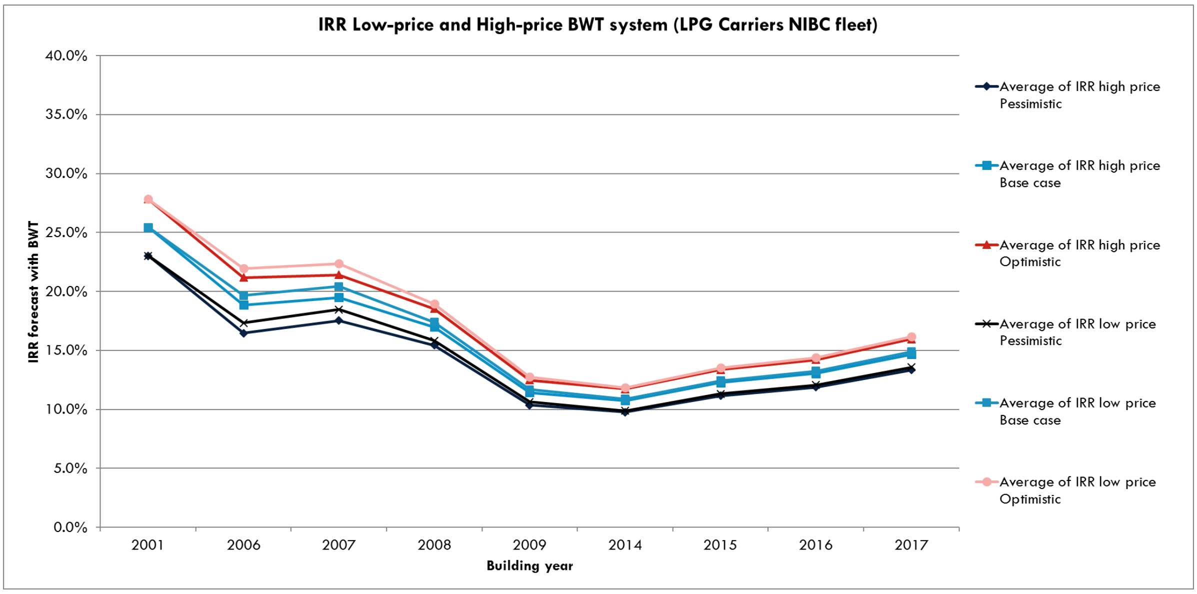


Figure 9.15: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of NIBC's portfolio of LPG carriers.

Figure 9.15 shows that the impact of the high-price BWT system compared to the low-price system is merely visible for all vessels younger than 10 years old. In this case the vessel value is very high compared to the investment needed for the installation of a ballast water treatment system.
The drop in forecasted IRR in this figure is solely based on the market prospects from MSI [**?**]
The forecast also show that for the product tankers, the IRR with a high-price system in a pessimistic market will stay above 9.9% with a cost of capital of around 9% this shows a very good prospect for all LPG carriers in NIBC's portfolio.

Figure 9.16 shows the IRR for the world fleet of LPG carriers. Unless NIBC's portfolio suffered more impact on IRR, it can be seen from this figure that the actual IRR is still above average of the world fleet, except for the vessels built in 2009 and 2014.

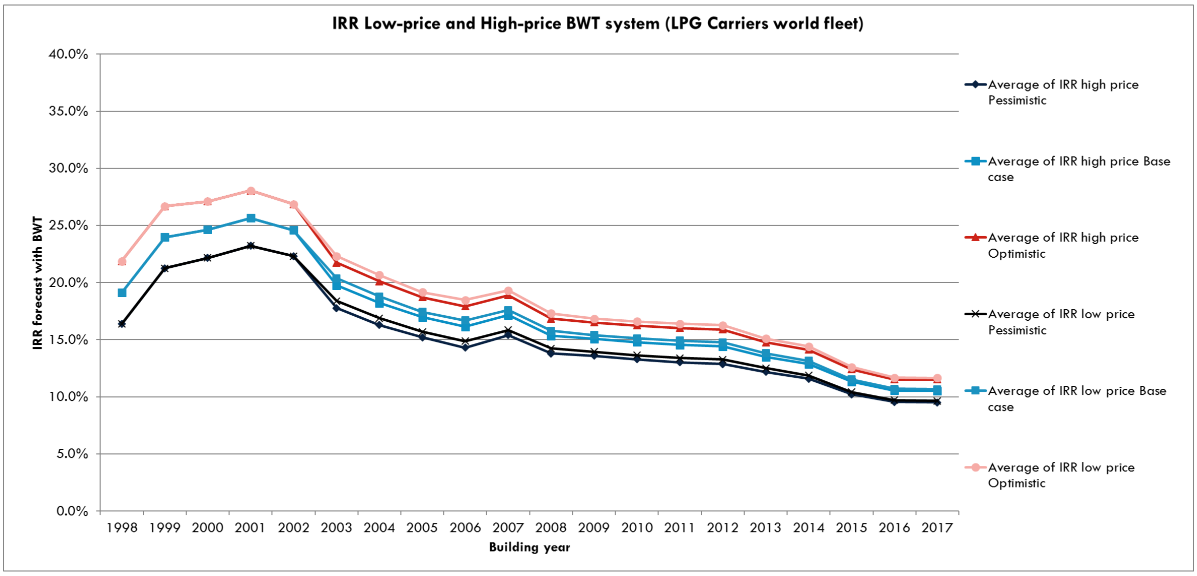


Figure 9.16: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the world fleet of LPG carriers.

9.5. Crude tankers

The NIBC fleet covers 32 crude tankers which covers around 11% of the entire fleet.

9.5.1. Δ IRR

The Δ IRR for the crude tankers of NIBC's portfolio is shown in figure 9.17.

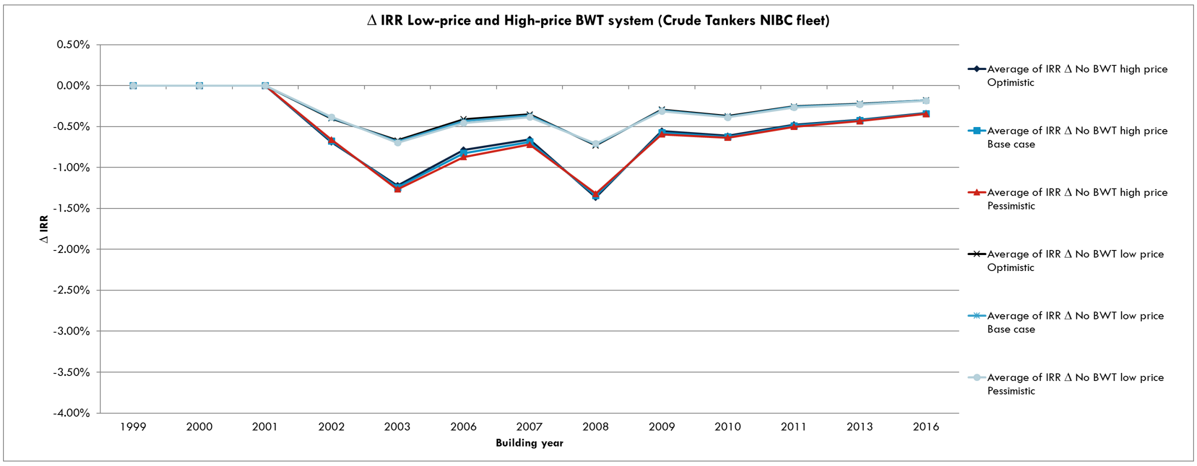


Figure 9.17: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of Crude tankers.

Knowing that 10 out of the 32 crude tankers is built before 2003, it can be seen from figure 9.17 that almost none of them will suffer from the ballast water treatment convention. The impact shown for the one vessel build in 2002 is due to the fact that according to the tool, the owner has to install a ballast water treatment system just a few month prior to the end of its lifetime. This impact can be neglected as it is not expected that the owner will install a system for the last months of its lifetime. The figure shows an impact on the IRR for the 2003 built vessels between -1.2% and -0.6%. A 2016 built vessel shows an impact between -0.3% and -0.2%. Again a linear correlation between the building year/age of the vessel and the Δ IRR can be found. For the crude tankers, similar impact is shown as with the product tankers. This is confirmed by the fact that the ratio between the average price of the crude tankers and the average cost of ballast water treatment installation is almost equal to the ratio for the product tankers.
The actual portfolio of crude tankers that need to install a BWT system is very small. The impact of a single vessel that needs to install the system on short notice will have greater impact on the average Δ IRR. This can be seen in 2003 and 2010 where in both cases, one vessel has to install the BWT system in 2020 instead of 2020.

Figure 9.18 shows the impact on IRR for the crude tankers of the world fleet. The impact on IRR for the crude tankers of NIBC's portfolio is almost equal to the average world fleet impact. In 2008 the world fleet shows a more extreme impact whereas NIBC's vessels from 2008 even suffer around 0.5% more. A vessel built in 2003 shows an impact between -1,3% and -0,7%.

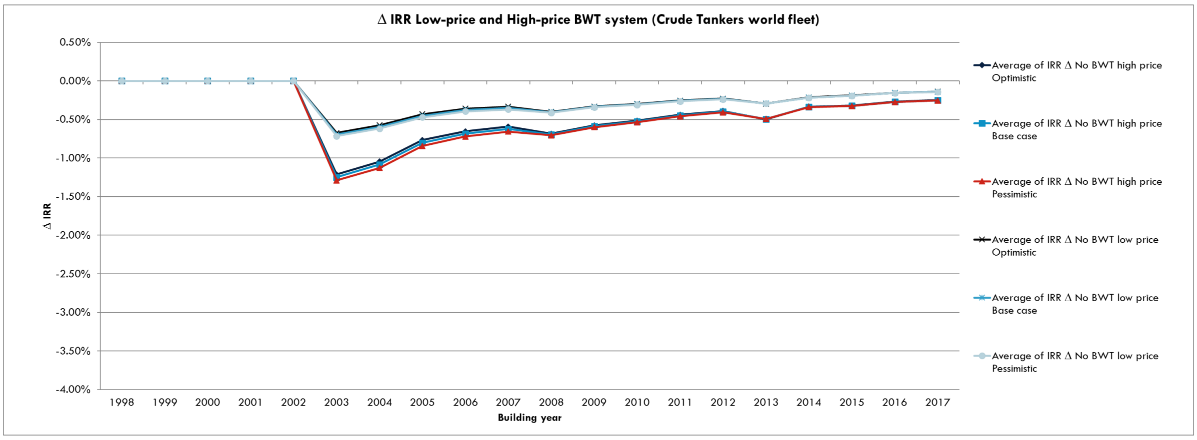


Figure 9.18: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of Crude tankers.

9.5.2. IRR

The forecasted IRR's that the crude tankers are able to get with the installation of a ballast water treatment system is shown in figure 9.7.

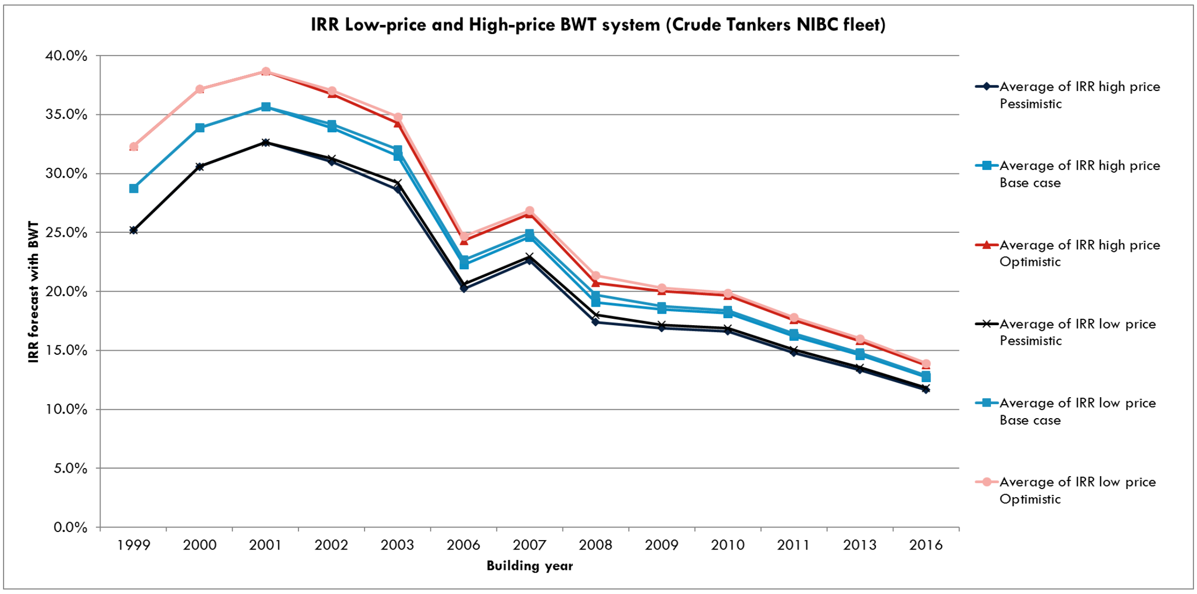


Figure 9.19: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of NIBC's portfolio of Crude tankers.

Figure 9.19 shows that the impact of the high-price BWT system compared to the low-price system is merely visible for all vessels. The ratio between the value of the vessels and the cost of BWT installation is equal to that of product tankers. The difference here can be found in the time charter rates, which are much higher for the large crude tankers compared to the product tankers. With these high returns, the difference of the impact of a high or low price ballast water treatment system can almost be neglected.
The sudden drops in IRR in this figure are solely based on the market prospects from MSI [**?**]
The forecast also show that for the product tankers, the IRR with a high-price system in a pessimistic market will stay above 11.8% with a cost of capital of around 9% this shows a very good prospect for all crude tankers

in NIBC's portfolio.

Figure 9.20 shows the IRR for the crude tankers of the world fleet. It can be seen that the older vessels built in 2001 perform better compared to NIBC's portfolio. The IRR's for the rest of the vessels show approximately the same pattern.

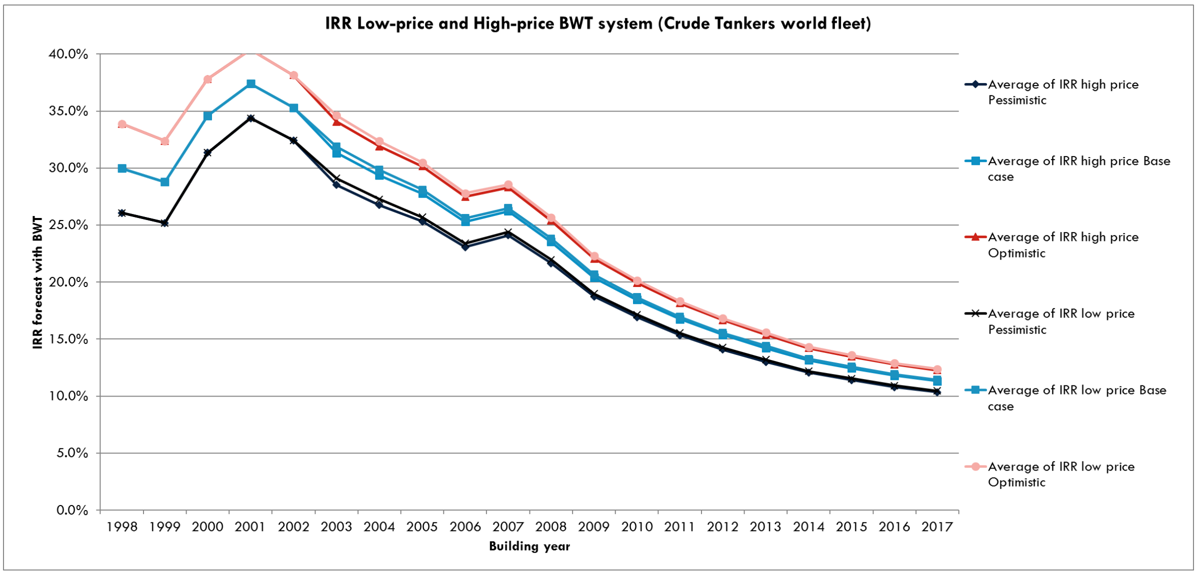


Figure 9.20: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the world fleet of Crude tankers.

9.6. Container carriers

The NIBC fleet only covers 8 container carriers which covers almost 3% of the entire fleet.

9.6.1. Δ IRR

The Δ IRR for the container carriers of NIBC's portfolio is shown in figure 9.21.

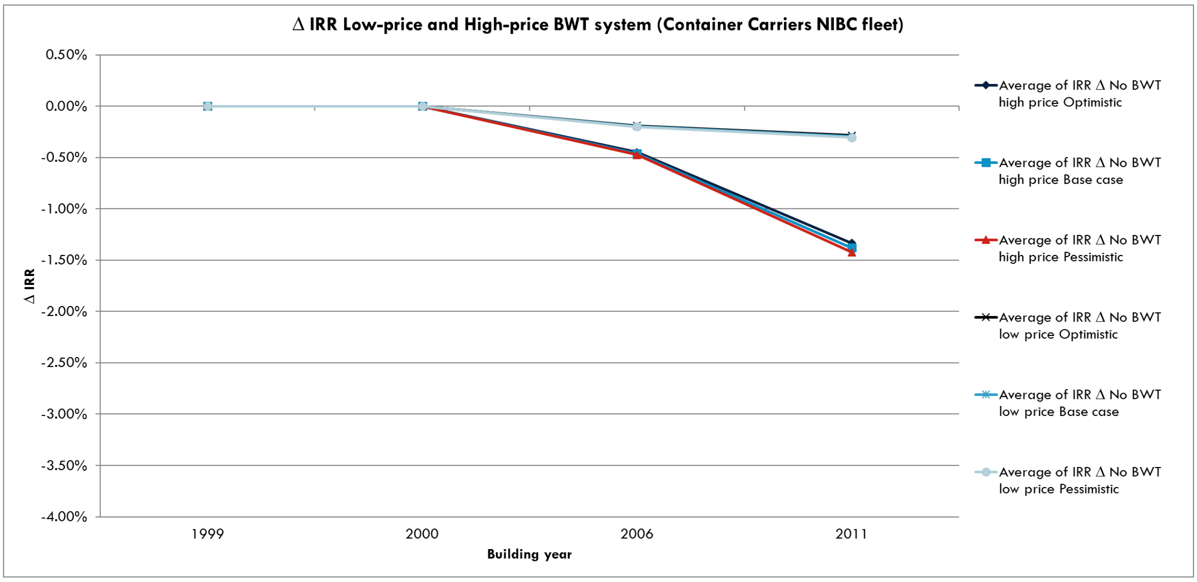


Figure 9.21: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of Container carriers.

Knowing that 5 out of the 8 container carriers are built in 2000 and before, it can be seen from figure 9.21 that none of them will suffer from the ballast water treatment convention. Only three vessels remain, 2 of which are built in 2006 and one in 2011. The figure shows an impact on the IRR for the 2006 built vessels between -0.5% and -0.2%. A 2011 built vessel shows an impact between -1.4% and -0.3%. No real correlation can be found for the container carriers as there are too little vessels in the portfolio which need to install a ballast water treatment system.

The big difference between the two vessels from 2006 and the one built in 2011 can be lead back to the size of the vessels. The two 2006 vessels are ten times larger than the 2011 vessel. With the knowledge from table 9.1 as discussed before, it can be concluded that for the larger vessels the BWT system costs relatively less than the smaller vessel.

Figure 9.22 shows the impact on IRR for the container carriers of the world fleet. As NIBC's portfolio contains only 3 vessels built after 2002 this could not give a trend for the container carriers. With the output of the tool for the world fleet, a clear trend can be found. The impact can range from 2.4% to 0.5% regarding the age of the vessel. The two vessels from NIBC's portfolio suffer around 0.5% against the world fleet with an average of 1.5%. The one younger vessel from 2011 shows around 1.4% impact against 0.7% for the world fleet.

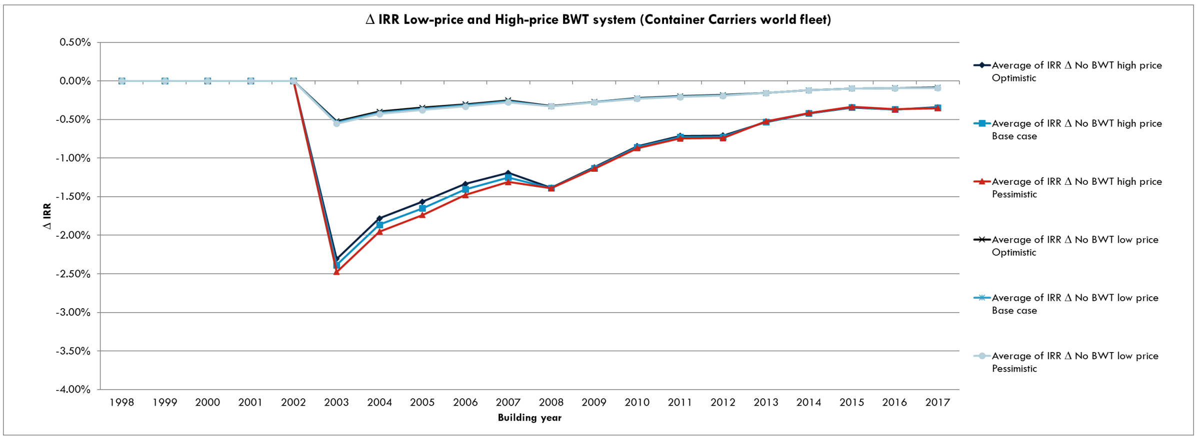


Figure 9.22: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet of Container carriers.

9.6.2. IRR

The forecasted IRR's that the container carriers are able to get with the installation of a ballast water treatment system is shown in figure 9.23.

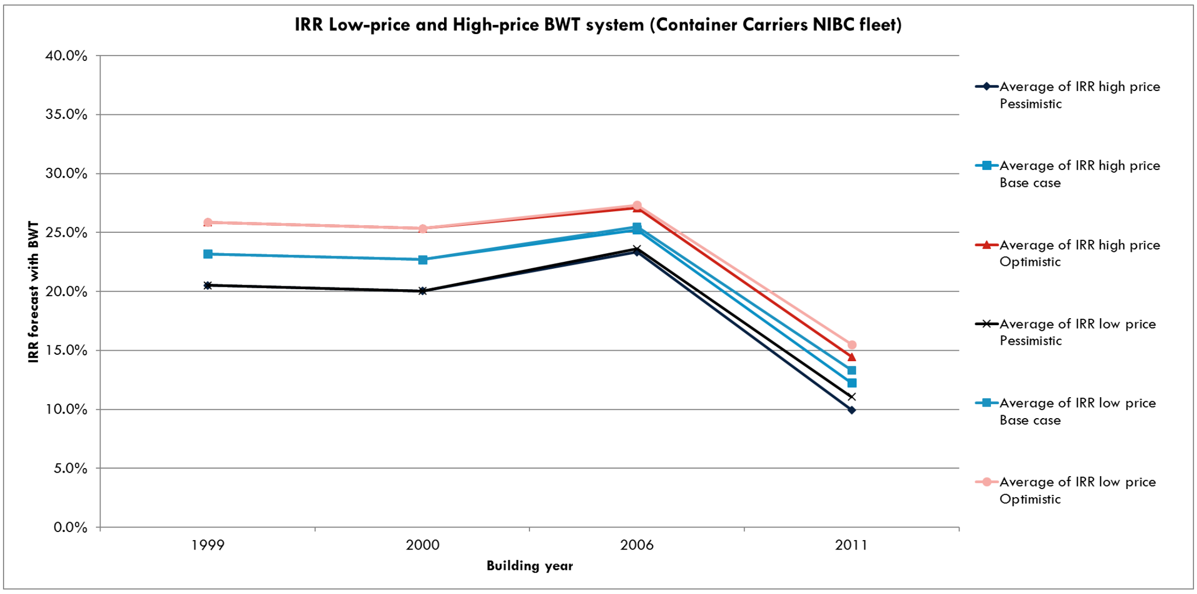


Figure 9.23: Overview of the forecasted IRR with the installation of a ballast water treatment system,high-price and low-price, of the NIBC portfolio of container carriers.

Figure 9.23 shows that the impact of the high-price BWT system compared to the low-price system is merely visible for the 2006 vessels. The 2011 vessel shows more difference on the impact of a low-price and high-price ballast water treatment system. This has the same reason as for the impact of the BWT system itself.
The forecast shows that the 2006 vessels will have an IRR of at least 23.6% which is a very good prospect. For the 2011 vessel the IRR will at least be 8.8%.

Figure 9.24 shows the IRR for the container carriers of the world fleet. High returns can be seen especially for the older vessels upto building year 2012. The younger vessels decline fast in IRR as prices and rates are expected to drop.

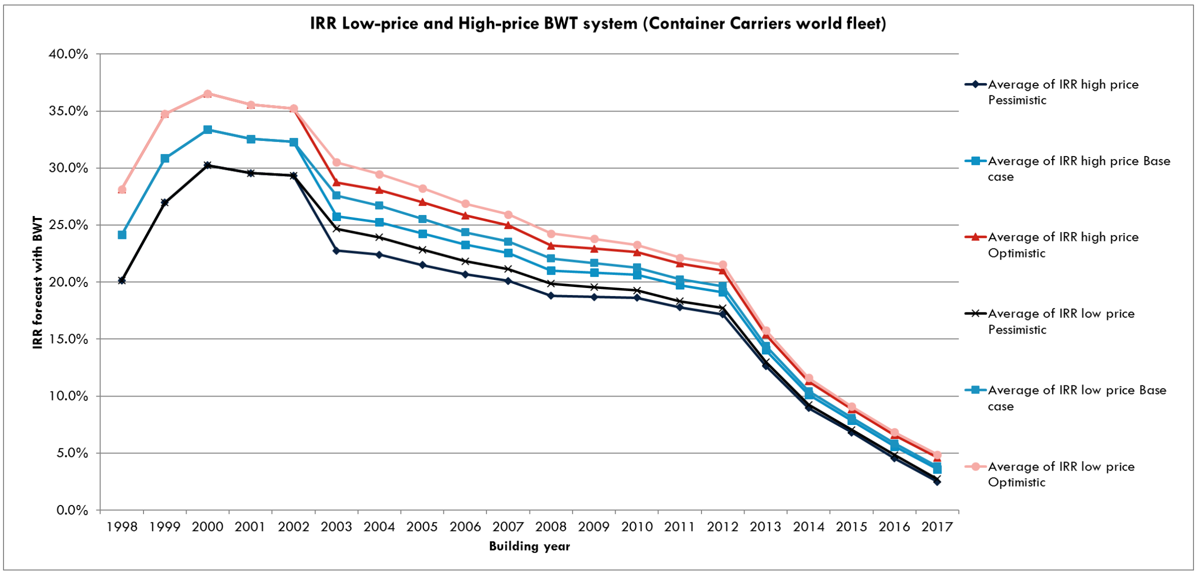


Figure 9.24: Overview of the forecasted IRR with the installation of a ballast water treatment system,high-price and low-price, of the world fleet of container carriers.

9.7. Consequences on delayed implementation dates and USCG approval

As from June 2017 it is still not clear whether the IMO BWM convention will enter into-force as planned. This, together with the need for stricter regulation on BWT systems according to the IMO, resulted in a lot of uncertainty. Furthermore will the USCG regulation also have an effect on part of the fleet. This section will explain possible outcomes and the impact it will have.

9.7.1. Postponing the implementation date

In MEPC 71, which is a meeting organised by the IMO from the 3rd to the 7th of July 2017, the issues concerning the implementation of the convention will be discussed. The International Chamber of Shipping (ICS) asked the IMO to listen to the proposal from multiple governments, which want to postpone the implementation date by two years. The secretary general Peter Hinchliffe commented: *"If this pragmatic proposal is agreed, this would allow shipping companies to identify and invest in far more robust technology to the benefit of the marine environment."*.

When the regulation will be postponed by two years, a lot of shipowners can sail their vessel until the end it its lifetime. When the implementation date is postponed for two years and it is still possible to renew the IOPP just before, vessels only have to comply in seven years from now. Because the tool is made generic, it is easy to change the implementation date of the regulation. All the figures of the analysis for a 2 year postponement can be found in appendix D. Figure 9.25 shows the impact on IRR for the bulk carriers of NIBC's portfolio when the implementation date is set on the 7th of September 2019.

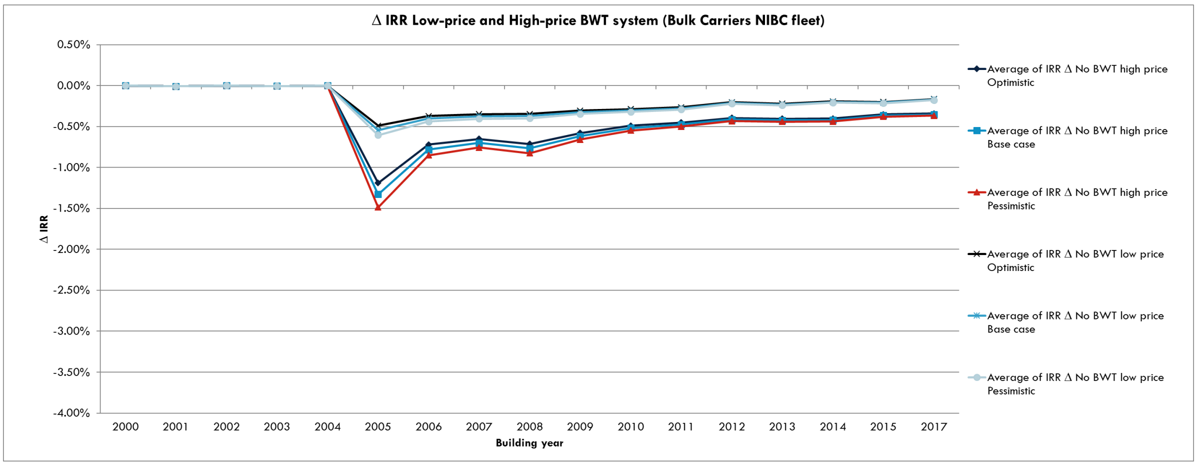


Figure 9.25: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of bulk carriers when the implementation date is set at 7/9/2019.

Figure 9.25 shows that vessels build until 2004 suffer no impact on average of the BWM convention. This postponement of two years without any impact is obvious for the change in implementation date. What can also be seen is that the actual impact is is also smaller for the vessels build in 2004. This is caused by the fact that shipowners now all have the opportunity to perform an IOPP renewal and postpone the installation of a ballast water treatment system. The further progression of the figure show no unexpected outcome. It can be seen from this figure that with a postponement of only two years, the impact can be reduced significantly. This is also based on the fact that by taking time value of money into account, a postponement for an investment positively affects the IRR. This will be a big relief for a lot of shipowners.

9.7.2. Regulation only applies for new-build vessels

When the regulation only applies for new-build vessels it will have a large impact. The current fleet will not be impacted at all and the impact on new-build vessels will be so small that this will not interfere with the competitiveness of the vessels. The installation cost for a retrofit could reach almost 100% of the purchase cost as discussed in chapter 5. The installation cost for a new build vessels could almost be neglected because it will just be part of the building process. This would imply that the impact on the IRR would be cut in half. Chapter 9 showed that for the bulk carriers, which suffer the highest impact, that the impact for young vessels build in 2017, the impact of a BWT system would vary between 0.4% and 0.2%. This would imply that the maximum impact for new-build vessels vary between around 0.2% and 0.1%. This is a very small impact when comparing it to the impact of a change in T/C rates, Opex or vessel price.

9.7.3. What if the USCG regulation applies to all vessels?

This report is focussed on the impact of the IMO BWM convention. The U.S. Coast Guard maintains a stricter regulation compared to the IMO. The implementation schedule is not linked to the IOPP renewal but to the special survey, making it impossible to postpone the installation of a BWT system. Figure 9.26 shows the impact on IRR for bulk carriers from NIBC's portfolio when all vessels have to comply with the USCG regulation.

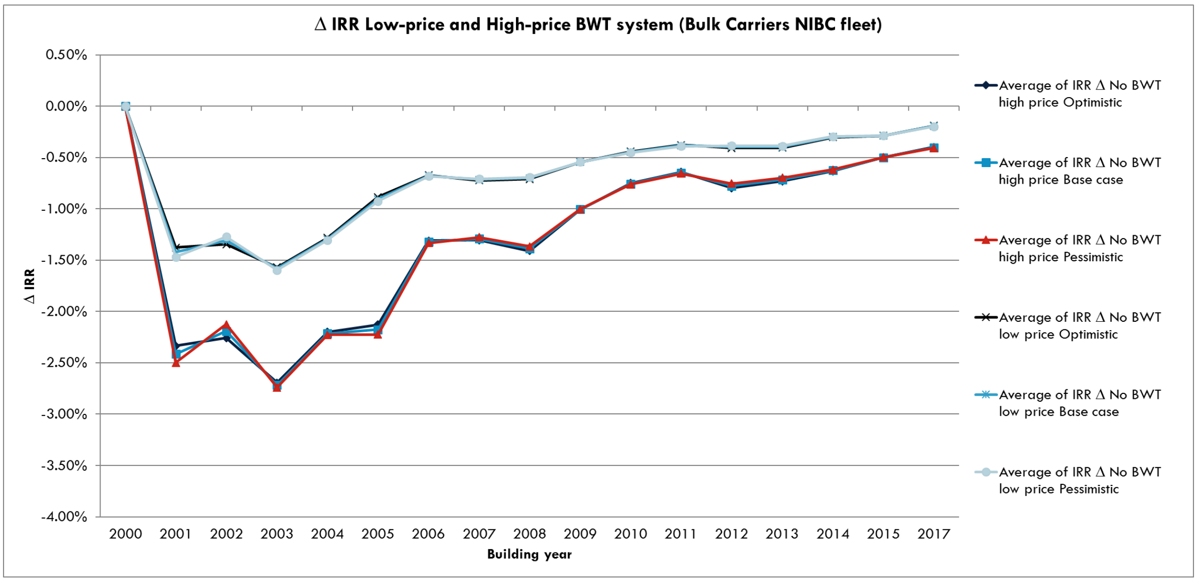


Figure 9.26: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio of bulk carriers when all vessels have to comply with the USCG regulation.

The most important thing that can be noticed is that there are no vessels that suffer no impact from the regulation in contrast to the IMO regulation. All the figures for the analysis with USCG regulation can be found in appendix E.

9.8. Analysis

This chapter the impact on IRR for the the NIBC fleet is discussed and compared to the world fleet. By analysing the impact and the market position for each vessel-type, it can be seen which vessels are impacted most and will face difficulties paying debt service to the bank. Figure 9.27 shows an overview of the average impact on the different vessel-types in NIBC's portfolio whereas in figure 9.28 the same graph for the world fleet is shown.

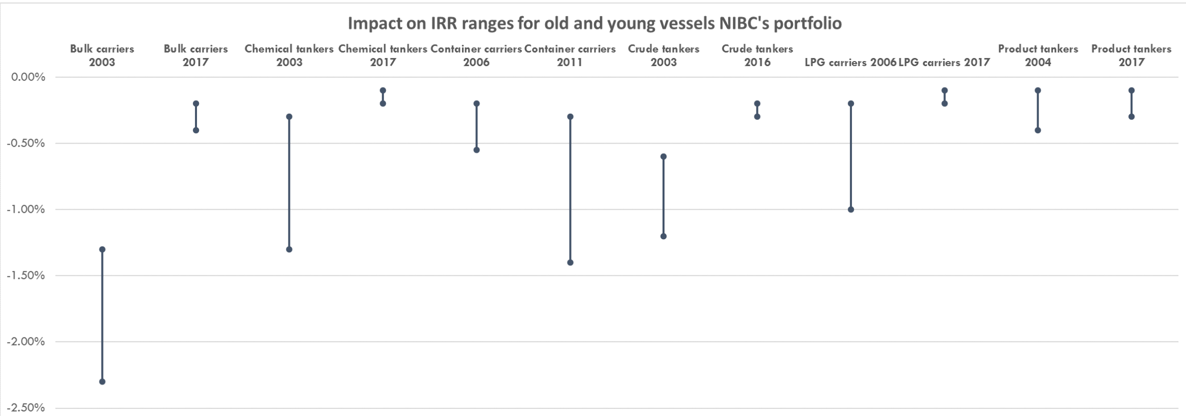


Figure 9.27: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio.

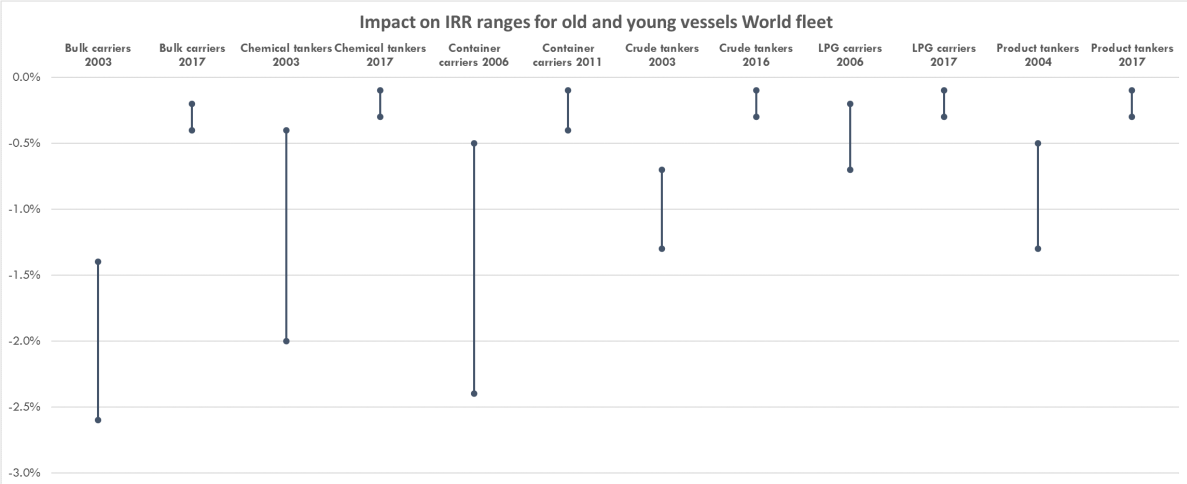


Figure 9.28: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet.

As can be seen from figure 9.27 and 9.28 the biggest impact on IRR is expected for the bulk carriers. As discussed before in section 9.2, this has to do with the construction of a bulk carrier. Bulk carriers are relatively cheap vessels with a high ballast water pump capacity. This implies that the ballast water treatment system will have a large impact on the value of the vessel of around 5,9%. For the other vessel-types this ranges between 1,9% and 4,8%. Also the T/C rates for bulk carriers are relatively low compared to the T/C rates from other vessel-types. As a result, bulk carriers have a lower earning capacity, the impact of the required investment to install a BWT system is therefore larger in terms of IRR. A specific analysis on the vessels that perform under a predefined IRR is conducted in chapter 10 in section 10.4, as these are considered high-risk vessels.

The possible delay of the implementation of the ballast water management regulation will have a positive impact for shipowners. All vessels that want to comply with the USCG regulation will suffer impact on IRR as the regulation is not linked to the IOPP renewal which can be delayed. This means that all vessels will feel the impact and the impact will be higher because there are no strategies to follow.

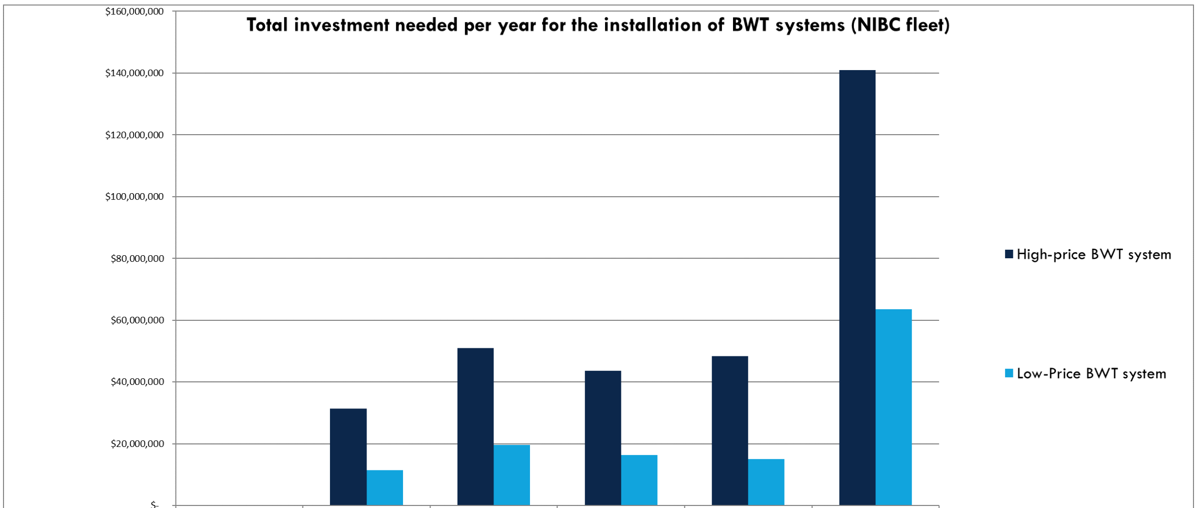
10

The impact of the BWM convention for NIBC

The previous chapters are mainly focused on the impact of the BWM convention for the ship owners of NIBC's portfolio. This chapter will discuss the impact the BWM convention might have for the bank. The first section will show an analysis of the total investment cost for all the ballast water treatment systems that should be purchased by NIBC's clients. The second section will show the loan to value which can be acquired by the ship owners and what impact the installation of a ballast water treatment system has on the LTV. The last section will discuss the vessels where the IRR dropped below a required IRR.

10.1. Total investment cost analysis of all ballast water treatment systems

The analysis discussed in chapter 8 showed that 230 vessels were to install a ballast water treatment system. This means that for 230 vessels an investment has to be made by the ship owners in the coming 5 years. When the ship owners are not able to pay for this investment they might ask for an additional loan. Figure 10.1 shows the total investment that is needed for the installation of all ballast water treatment systems on board of all vessels of NIBC's portfolio.



	No BWT needed	31-01-18	31-01-19	31-01-20	31-01-21	31-01-22
High-price BWT system	$26,000	$31,474,635	$50,970,408	$43,638,609	$48,304,348	$140,969,701
Low-Price BWT system	$26,000	$11,450,979	$19,557,698	$16,411,836	$15,047,124	$63,586,442

Figure 10.1: Overview of the total investment cost needed for installing BWT systems on the vessels of NIBC's portfolio.

Figure 10.1 shows the investment that is needed for BWT systems every year. Some of the vessels that do not need to install a ballast water treatment system do need a small investment for the IOPP renewal. The total cost of IOPP renewals is shown in the first column and will take place this year. Furthermore the figure shows that the largest total investments will take place in 2022. Depending on the ship owner, a low-price or high-price system will be installed. When considering a worst case scenario where all owners decide to invest in a high-price BWT system, the total investment costs for all vessels over 5 years time will be almost $ 315,000,000 The 2017 vessel value of all vessels that need to have a BWT system installed is around $ 4,930,000,000 The total investment that is needed for the installation of high-price ballast water treatment systems over 5 years impacts the total value of the fleet by 6.4%. An overview is shown in table 10.1.

Total investment needed just for IOPP renewal	$ 26,000
Total investment needed for high-price BWT (including IOPP)	$ 315,000,000
Total investment needed for low-price BWT (including IOPP)	$ 126,000,000
Total vessel value	$ 4,930,000,000
Total impact low-price BWT as a percentage of the vessel value	2.6 %
Total impact high-price BWT as a percentage of the vessel value	6.4 %

Table 10.1: Total investment cost and impact on the entire NIBC portfolio

Figure 10.2 shows the total investment that is needed for installing ballast water treatment systems on the selection of the world fleet.

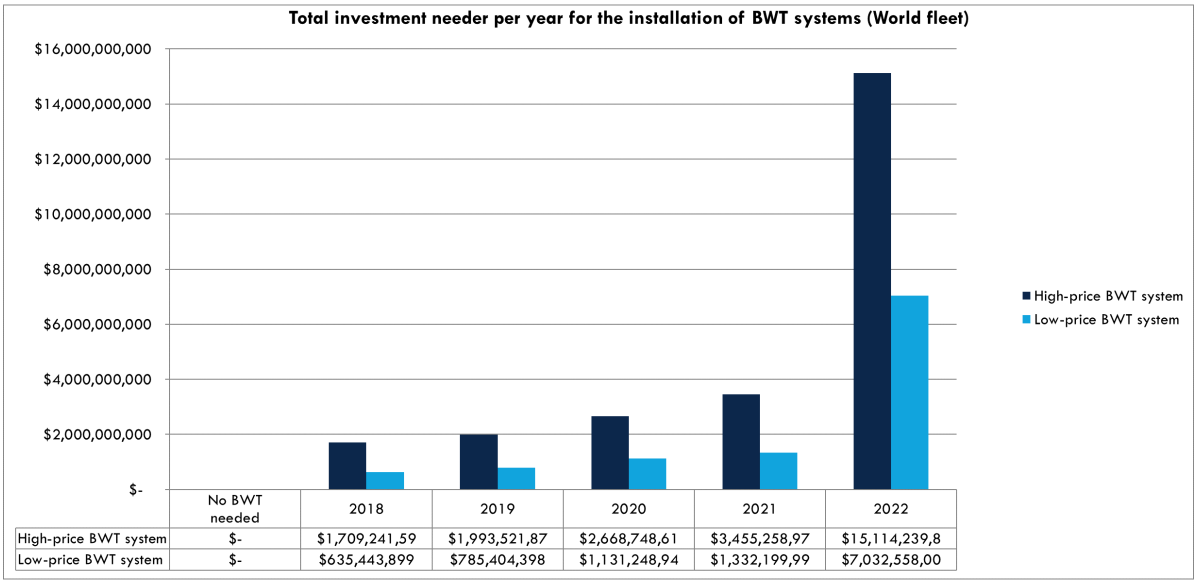


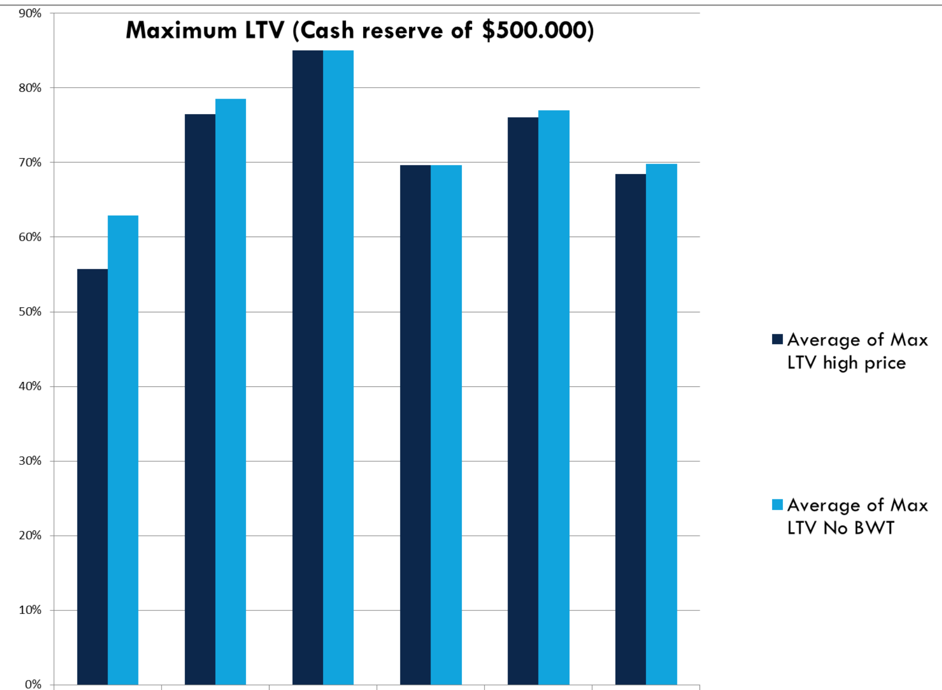
Figure 10.2: Overview of the total investment cost needed for installing BWT systems on the world fleet.

Total investment needed just for IOPP renewal	$ 0.0
Total investment needed for high-price BWT (including IOPP)	$ 24,941,000,000
Total investment needed for low-price BWT (including IOPP)	$ 10,917,000,000
Total vessel value	$ 383,252,000,000
Total impact low-price BWT as a percentage of the vessel value	2.9 %
Total impact high-price BWT as a percentage of the vessel value	6.5 %

Table 10.2: Total investment cost and impact on the world fleet.

10.2. Impact on the loan to value

The installation of a ballast water treatment system can impact the maximum to acquire loan as the cash flow models change with the investment of a BWT system. The tool calculated the maximum loan to value which the owner could afford with a cash reserve of $ 500,000 This is done for all vessels that need to install a ballast water treatment system. Figure 10.3 shows the impact on the maximum loan to value caused by the BWT system.



	Bulk carrier	Chemical tanker	Container carrier	Crude tanker	LPG Carrier	Product tanker
Average of Max LTV high price	56%	77%	85%	70%	76%	68%
Average of Max LTV No BWT	63%	79%	85%	70%	77%	70%

Figure 10.3: Overview of the maximum LTV with the investment of a BWT system compared to the hypothetical scenario without a BWT system for NIBC's portfolio.

Figure 10.1 shows that the container carriers and crude tankers are not impacted by the BWT system to have an impact on the maximum loan to value. For bulk carriers the biggest change in maximum loan to value. This shows the same large impact as on the IRR because of the relatively low vessel value and high price for a BWT system. Chemical tankers, product tankers and LPG carriers all show around 1 or 2% impact on the maximum loan to value. This is in accordance with the findings for the impact on IRR discussed in chapter 9.

10.3. Impact on portfolio size

As discussed in chapter 8, 21% of NIBC's portfolio will be sold or scrapped due to ageing or to gain the highest possible IRR within 5 years time. From the analysis it could be seen that 9% did not have to install a ballast water treatment system. This is an outflow in the portfolio of the bank which is expected. The remaining 12 % are vessels that are either being sold because of a favourable price or scrapped before the end of its lifetime. The 11.97% that is being sold because of a favourable price is expected to result in a refinance with the shipowner. When the shipowner sells its vessels with a high return, it is probable that new vessels will be bought. For at least some of these new vessels it is expected that NIBC will offer a loan again. The 0.3% of the portfolio, which is being scrapped, will not lead to new loans as the shipowner is most likely not able to pay for new vessels. This would result in a decrease in the number of vessels in the portfolio of between 0.3 and 12% in five years time. This is an average decrease of the number of vessels in the portfolio between 0.06 to 2.40% on a yearly basis.

The average replenishment of NIBC's portfolio is around 30% on a yearly basis. Around 20 % of this is based on the five year profile of the loan. On average every loan is repaid in five years time. This implies that after 5 years 100% of the portfolio is replenished. This comes down to a yearly replenishment of 20%. The other yearly 10% is caused by vessels that are being sold or scraped and thus prematurely ended. The 0.06 to 2.4% will barely make any difference in the conventional replenishment scheme.

10.4. High risk vessels

Some vessels will be impacted by the ballast water treatment system in such an extend that the IRR drops below a certain required IRR. As discussed in chapter 8 a common cost of capital is 9%. This is based on a 60% loan with interest of 5% and 40% own equity with a required return of 15% as discussed in chapter 8. When the IRR drops below 9% the own equity return will suffer. The interest on the bank loan can not change and the owner should accept a lower return on its own equity. This section will discuss the vessels that drop below an IRR of 7%, 8% and 9% due to the high-price BWT installation in a pessimistic market. These vessels are displayed in a table and discussed. Table **??** shows the vessels where the IRR dropped under 7%.

SECTION NOT DISCLOSED DUE TO CONFIDENTIALITY REASONS

11
Conclusions and recommendations

This chapter will discuss the general conclusions of the research on the impact of ballast water management on shipowners and banks. The goal of this thesis is to show the impact of the ballast water management convention for ship owners and NIBC as a bank. Furthermore recommendations are given for further research purposes.

11.1. Conclusions

The objective of this thesis is to clarify the impact on IRR of the ballast water management convention regulation and to give a vessel-specific recommendation on what strategy suits best. Both objectives are achieved by creating and applying a tool, which functions as a financial investment model.

11.1.1. The most important parameters when choosing a BWT system

When choosing a ballast water treatment system a lot of parameters have to be considered. The most important parameter is the sailing route of the vessel. When the vessel is only sailing in countries which did not ratify the convention, no BWT system has to be installed. The sailing route also determines the condition like the salinity, temperature and turbidity. The second most important parameter is the ballast water pump capacity, which has to be matched with the maximum flow capacity of the ballast water treatment system. All parameters should be considered as boundary conditions as most BWT systems are not able to perform treatment outside these boundaries. The choice of a ballast water treatment system for the use of the tool is based on the ballast water pump capacity, the ballasting profile, the purchase cost and the operational costs. Furthermore when choosing a ballast water treatment system other parameters like the footprint of the system, the power requirements, pressure drops, installations in hazardous areas and the impact of the treatment system on piping and ballast tanks should be considered.
All of the mentioned parameters should be thoroughly investigated before choosing a ballast water treatment system. For the use of the tool the most important parameter is the ballast water pump capacity. Also the operating costs are taken into account. This will give an insight on the impact of the ballast water treatment system as it is assumed that the pricing of a BWT system is equal for different methods with the ballast pump capacity range of all NIBC fleet vessels.

11.1.2. The most promising approved BWT methods

The IMO approved 69 different ballast water treatment systems as from the end of 2016. There are a lot of treatment methods available, all with different pros and cons. All of the available methods are already used on land based applications. The biggest discrepancy lays in the fact that: power supply, time, on-board restrictions of chemicals and available space are limiting factors on-board a vessel. Filtration with a hydrocyclone, coagulation and flocculation seem to be too complex and do not seem suitable for the ballast water treatment application.
Because IMO and USCG regulation originates from an environmental motivation, chemicals do not seem to be a sustainable solution. The fact that extra precautions and regulations apply for the storage of these chemicals on board a vessel, together with the counter intuitive control of the environment with highly toxic chemicals, makes the chemical treatment methods an unlikely solution for this environmental problem on

the long term.

The most probable and sustainable solutions seem to be in the physical and mechanical treatment methods. A range of physical methods are either not performing according the USCG and/or IMO standards or too complex and expensive to realize on board a vessel. This would imply that only the UV, electro chlorination and deoxygenation treatment methods seem to be suitable and sustainable options.
The most common used ballast water treatment methods are: UV treatment and electrochlorination. Almost 50% of the approved systems make use of UV treatment. Electrochlorination is use by 17% of the approved systems. Only 8 % uses deoxygenation like the inert gas method. For these three methods it can be said that in general the UV systems are most applied on vessels with ballast water pump capacities upto 3,000 m3/h and deoxygenation is used for higher capacities. Everything in between can be resolved by the electrochlorination method. This is caused by the fact that the UV systems with a BWT flow capacity up to 2,000 m3/h have the smallest footprint. This is a very important parameter, especially for the smaller vessels. Purchase costs are almost equal to electrochlorination systems but the power consumption of an UV system is almost twice as big. That is why between 1,500 and 3,000 m3/h the electrochlorination systems become more attractive. The footprint of the electrochlorination systems are smaller compared to the UV systems but the Opex is lower. For flow rates over 3,000 m3/h, the inert gas system becomes interesting. The purchase cost of an inert gas system is much higher compared to UV and electrochlorination but it can handle high ballast water capacities as it is independent on the flow rates.

11.1.3. Choosing a ballast water treatment system

Chapter 4 analyses the 69 IMO approved BWT systems. It is expected that over time, less manufacturers will continue to manufacture these systems and provide service worldwide as certain systems will prevail over others. A total of eight ballast water treatment systems from different manufacturers is selected based on performance and company background. It is important that the manufacturer is financially healthy and globally represented to ensure sustainable and global service support. As it is expected that not all manufacturers will withstand, it is very important to choose a manufacturer which is believed to still be in business in 10 years time. When a manufacturer stops producing, the service on the BTW system can also stop. Spare-parts will extinct and the ship owner will pay a lot to fix any problems. An overview of the different systems, that are believed to be reliable and sustainable, is shown in table 11.1.

Treatment system	Manufacturer	Treatment method	Capacity range (m3/h)
PureBallast 3.1	Alfa Laval	Filtration + UV treatment	32 – 3,000
GLD BWTS	ColdHarbour	Inert gas	inf
Balpure	De Nora	Electrochlorination	500 - 20,000
RayClean	Desmi	Electrochlorination	300 – 3,000
Guardian	Hyde marine	Filtration + UV treatment	60 – 3,000
OBS	Optimarin	Filtration + UV treatment	167 – 3,000
GloEn-Patrol	Panasia	Filtration + UV treatment	1,000 - 3,000
Electro-cleen	Techcross	Electrochlorination	150 – 1,000
Aquarius UV	Wärtsilä	Filtration + UV treatment	50 – 1.000
Aquarius EC	Wärtsilä	Electrochlorination	750 – 3,300
Invasave300	Damen	Filtration + UV treatment	300

Table 11.1: Treatment systems with capacity ranges

Table 1 also shows the alternative Invasave300 solution, which is manufactured by Damen. This alternative system is manufactured for service providers to collect ballast water and treat it outside of the vessel. The ship owner is not obliged to install a ballast water treatment system when this service is used. This solution seems not suitable for the vessels of NIBC's portfolio since the capacity is still very limited and there is uncertainty whether all ports are able to provide this service. This treatment solution is considered more as an alternative option for smaller vessels or when the BWT system of a vessel malfunctions.

11.1.4. The results of the cost study on ballast water treatment systems

A cost study on the purchase cost, installation cost and Opex is performed on the ballast water treatment systems shown in table 11.1, except for the alternative solution. This cost study showed no substantial price differences between the UV and EC systems for different ballast water pump capacities upto around 3,000 m3/h. The inert gas system shows a significant higher price. Tankers which are already equipped with an inert gas system should install a separate inert gas system for BWT, as the inert gas system has to be IMO/USCG approved for BWT purposes. Nevertheless, it is capable of treating large amounts of ballast water, which reduces the price per m3 treated. Figure **??** shows the purchase, engineering and installation cost in a European yard plotted against the maximum flow capacity of the BWT systems.

FIGURE NOT SHOWN DUE TO CONFIDENTIALITY REASONS

The installation cost of a BWT system is very much dependent on the yard in which the installation is performed. Chinese yards show installation costs that are around 4,5 times more competitive compared to European yards.

The yearly consumables of the systems range from $1,500 for a 1,000 m3/h EC system and $20,000 for a 6,000 m3/h UV system according to the performed cost study. From this cost study it can also be concluded that the electrochlorination method only requires around half of the power compared to a system using UV treatment.

With this cost study, a range of prices can be given for each ballast water pump capacity. For the use of the tool, the two most extreme prices are left out to provide a representative price range. The second least expensive and second most expensive option is then used for the analysis of the tool. In the tool this is called a high-price and a low-price system. This represents a price range for which a ballast water treatment system could be purchased and installed and can be seen as a sensitivity analysis.

11.1.5. Strategies to follow

In this research 23 possible strategies are discussed. For each strategy a potential gain and or loss is discussed. The strategies are divided into three different scenario's: No ballast water treatment system needed, sell or scrap the vessel and installation of a ballast water treatment system. In this research it is assumed that the price of a ballast water treatment system remains stable. With this assumption that are made, 6 strategies remain feasible. These six strategies are:

- Strategy 2 (Installation of a BWT system during next dry-dock (first planned dry-dock after 8th of September 2017))
- Strategy 4 (Sell/scrap vessel before second dry-dock (first planned dry-dock before 8th of September 2017))
- Strategy 5 (Installation of a BWT system at second dry-dock (first planned dry-dock before 8th of September 2017))
- Strategy 16 (IOPP renewal, perform regular dry-dock and sell/scrap vessel before next IOPP renewal)
- Strategy 17 (IOPP renewal, perform regular dry-dock and install BWT before next IOPP renewal)
- Strategy 21 (Sell/scrap vessel before first dry-dock (first planned dry-dock after 8th of September 2017))

These strategies are implemented in a tool, which is able to calculate the IRR for each strategy to follow. According to the highest IRR, an ideal vessel-specific solution is proposed.

11.1.6. An ideal vessel-specific strategy by the use of a tool

A tool is created to find the best strategy for each vessel based on the internal rate on return. It also calculates the impact of the ballast water treatment system on the expected IRR. The tool generates cash flow models for each strategy to compare based on basic vessel parameters. With the DWT, the building year, the vessel-type and the last known survey the ballast water pump capacity can be calculated. With these parameters, a cash flow model for each strategy can be created with the forecasted rates and vessel prices from MSI [**?**]. The strategy for each scenario with the highest forecasted IRR is then selected. The IRR is calculated with the following assumptions:

- The vessel has a 20 year lifetime

- The investment is equal to today's value
- Revenues and Opex are based on MSI values [**?**]

To make a comparison, a cash flow model of the vessel without the installation of a BWT system is created. The difference between this IRR and the highest IRR with the installation of a ballast water treatment system is considered the impact of the ballast water management convention. Besides the IRR, the tool can calculate the maximum loan amount for which the ship owner is still able to pay debt service with the cash flow of the vessel. A cash-reserve, if available, can be added to this calculation.
The output of the tool is a database of the vessels from NIBC's portfolio with the expected IRR. The database contains IRR's of all different cases and scenario's and suggests which strategy to follow. The tool is build up in such a way that quarterly available MSI [**?**] data can be updated. Also new assumptions, like a change in cash-reserve, or the going into-force date of the BWM regulation are easily adaptable. The tool is flexible, user-friendly and can be used for a wide range of applications for future use by the bank.

11.1.7. The impact on the shipowners of NIBC's portfolio

Using the tool an analysis is done on the NIBC fleet. Outcome of the analysis to NIBC's portfolio shows that 79% of the portfolio should install a ballast water treatment system. 12% off the vessels should be sold or scrapped and 9% of the vessels do not have to install a BWT system at all. As expected, the strategy that postpones the investment in a BWT system with the smallest investment is chosen. This can be realised either by planning the next special survey before the going into force date or by an early renewal of the IOPP certificate. In certain cases, the vessel will get a higher IRR when selling the vessel before the first dry-dock. This is the case when an up-tick in the vessel price is expected for this specific vessel. The vessel value of today is assumed to be the initial investment. When an up-tick in vessel value is expected, the IRR for the vessel can be very high when selling the vessel before next dry-dock.
When comparing the impact of the BWT system on the IRR, a linear correlation between the age of the vessel and the impact can be found. This correlation is plotted and discussed for each of the five identified vessel-types. The largest impact is expected for bulk carriers. The average impact on IRR for each vessel type for NIBC's portfolio and the world fleet is shown respectively in figure 11.1 and 11.2. Figure 11.1 and 11.2 shows the range of impact on IRR for older and younger vessels, for both a high-price and low price ballast water treatment system.

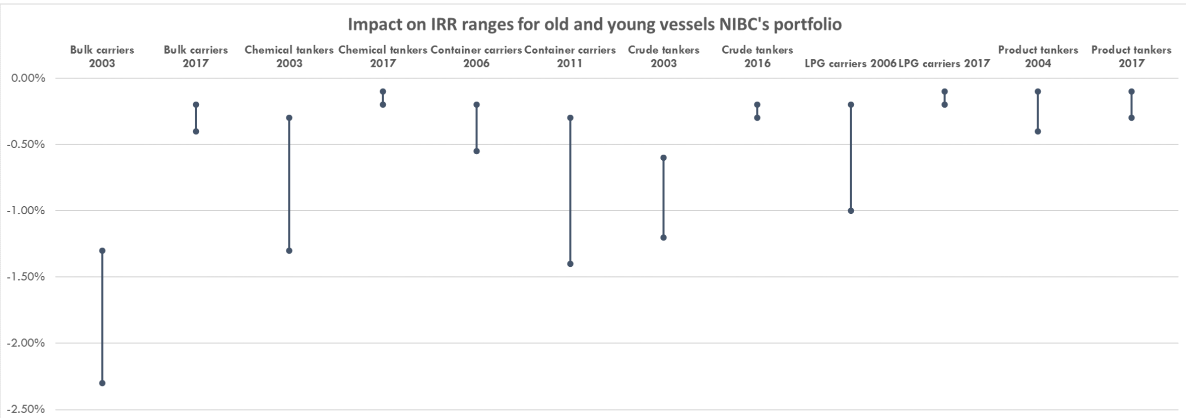


Figure 11.1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio.

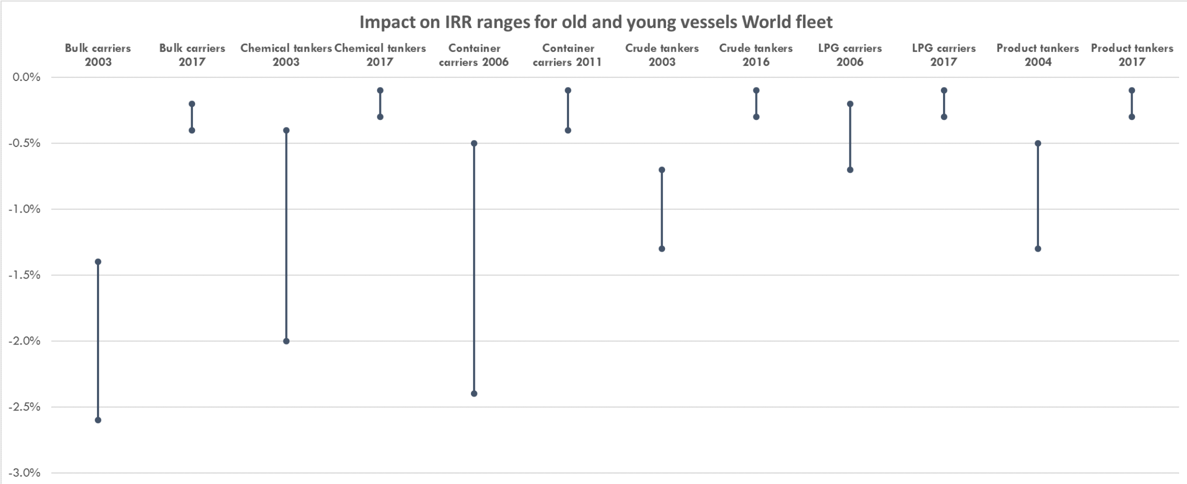


Figure 11.2: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the world fleet.

The main reason is the construction of a bulk carrier. Bulk carriers are relatively low priced vessels with a high ballast water pump capacity. This implies that the investment of a ballast water treatment system will have a large impact on the value of the vessel. Also the T/C rates for bulk carriers are relatively low compared to rates for other vessel-types. This implies that bulk carriers will suffer the biggest impact.

11.1.8. The impact for NIBC as a bank

The impact of the total required investment for all vessels, within NIBC's portfolio, to comply with the BWM convention can be calculated. As not all ship owners will be able to make the investment for a BWT system, the bank may need to take action. Table 11.2 shows the total investment which is needed in the next five years. This investment represents between 2.3 and 5.2 % of the value of the vessels as shown in table 11.2.

Total investment needed just for IOPP renewal	$ 26,000
Total investment needed for high-price BWT (including IOPP)	$ 315,000,000
Total investment needed for low-price BWT (including IOPP)	$ 126,000,000
Total vessel value	$ 4,930,000,000
Total impact low-price BWT as a percentage of the vessel value	2.6 %
Total impact high-price BWT as a percentage of the vessel value	6.4 %

Table 11.2: Total investment cost and impact on the entire NIBC portfolio

The installation of a BWT system can also impact the maximum loan amount as the cash flow models change with the new investment. The tool calculates the maximum loan to value for each vessel with a cash reserve of $ 500,000, which is common in NIBC's financing structures. This is done for all vessels that need to install a ballast water treatment system. The results show that container carriers and crude tankers are not impacted by maximum loan by the BWT system. As expected, bulk carriers show the biggest change in maximum loan to value of 7%. This is in line with the large impact on the IRR. Chemical tankers, product tankers and LPG carriers all show around 1 % to 2 % impact on the maximum loan to value. This is in accordance with the findings for the impact on IRR which can be seen in figure 11.1 and 11.2.

Overall it can be said that the impact of the ballast water management convention is significant but not causing more than 3% of the world fleet to be scrapped. This is based on the assumption that the shipowners have enough liquidity for the investment of a BWT system and will only scrap when this is the most ideal solution, giving the shipowner the highest possible IRR. The actual number of vessels that will be scrapped will be higher as not all shipowners will have enough liquidity to install a BWT system and not all owners will be able to find a buyer for the vessel.

11.1.9. Further applications of the tool

The tool that is created for this research is able to create cash flow models based on very basic ship parameters. NIBC can use this tool to quickly identify high-risk vessels that have a higher probability to have a shortfall in cash flow, this could lead to a non-performing loan. The tool makes it easy to review the existing portfolio on performance.

With the world fleet analysis, the bank is able to find new prospects. The tool gives a forecasted IRR which represents the expected profitability of the vessel. In this way, high performing vessels, which are in line with NIBC's strategy, can easily be identified. For these new prospects the maximum loan is also calculated giving the bank an idea of the possible maximum loan which can be obtained.

The bank can also use this tool for calculating the impact of another large investment for the entire fleet. The list of ballast water treatment systems can easily be adjusted with another investment like a scrubber. This will be further evaluated in the following section.

11.2. Recommendations

In this section, recommendations following from the conclusions are given. The recommendations are suggestions on future research concerning this subject. Each recommendation will be explained briefly.

11.2.1. Two way approach on the investment

Every vessel is seen as an investment today. These vessels are actually bought in the past and the cash flow of the past will influence the choice of the shipowner. From the NIBC portfolio, 11% of the vessels should be sold and 1% should be scrapped, as discussed in chapter 8. The 11% of the vessels that should be sold should be approached on a different way. These vessels can get a high IRR caused by an up-tick of the vessel price. This is correct when the vessel is bought today but in reality the vessel is bought in the past. The shipowner will likely sail with the vessel instead of selling it as the vessel is bought for a higher price in the past. To solve this problem, a second approach should be executed for the these vessels. In this approach the actual investment in the past is filled in and the cash flow model is created for the entire lifetime of the vessel.
The build-in option in the tool to take the average vessel price over the last 15 years is another way to approach it. In addition, the entire financial situation of the company should be considered with all vessels involved to get a better insight in the companies decisions.

11.2.2. Use of the tool for sulphur emission regulation

A fuel oil sulfur cap is set at 0.5% m/m by the IMO for the first of January 2020. This implies that vessels should sail on low sulfur compliant fuel oil or install a scrubber to remove the sulfur from the exhaust gasses. The additional cost and impact of the installation of scrubbers or Selective Catalytic Reduction (SCR) systems can also be calculated with the use of the tool created for this research. Instead of a list of ballast water treatment systems, a list of scrubbers and SCR systems can be used. Any investment that has to be made can be incorporated in the tool, the installation of a scrubber is an example of this.

11.2.3. Impact on the environment

The ballast water treatment convention is initiated to protect the environment and safe the local ecosystems. When a regulation implies that large machinery has to be installed, this raises questions. Manufacturing these systems will leave a carbon footprint which should be taken into account when considering the environmental impact. The BWT systems need electricity which, in most cases, will be generated by the main engine. The emission for running the BWT system should also be taken into account. Further research has to be carried out to investigate the impact on the environment from both the carbon footprint and the emissions that are produced during operation. This research could reveal whether the regulation results in a positive effect on the environment or not.

11.2.4. Further research to the exemption for vessels

All of the vessels from NIBC's portfolio have to comply with the BWM regulation. For some other vessels there are exemptions as discussed in chapter 1. Research can be done to investigate the possibilities for small non sea-going vessels and vessels that only operate in same-risk areas. These same-risk areas, which imply that the eco-systems are the same, are not all defined and ship owners have to prove the fact that an area can be considered as same-risk. Research should be done to evaluate the possibilities in receiving an exemption for a same-risk area.

11.2.5. Alternatives for complying with the BWM regulation

Next to ballast water treatment systems that have to be installed on board, there are also alternatives to comply with the BWM convention ass discussed in chapter 4. One alternative solution, the Invasave300 manufactured by Damen, is discussed but not exploited enough to do a cost analysis. When more vessel-specific data is known regarding the ballasting profile, a cost study can be done to calculate the turnover point for choosing an alternative BWT system over the installation of a BWT system. This research can be executed when service providers from alternative systems are more ubiquitous.

11.2.6. Implement all approved ballast water treatment systems in the tool

All 69 available ballast water treatment systems could be incorporated in the tool. A more thorough cost analyses should be executed to gather data for all the available BWT systems. In this way a shipowner can select the desired ballast water treatment method to have a more detailed forecast. This could have a small impact on the older vessels. For a new-build vessel the difference between a low-price and high-price system results in a difference in IRR of around 0.2% as can be seen from the analysis in chapter 9. This implies that the minor impact caused by the price for selecting a specific ballast water treatment method is going to make very little change.

11.2.7. More vessel types

More vessel types like LNG carriers can be added to the tool to be more complete. For this research this was not relevant as LNG carriers do not cover a sufficient part of the portfolio. These vessels have to be treated less generic than for instance a bulk carrier as its not just about the DWT. Most of the LNG carriers have contracts for almost the lifetime of the vessel. This makes it difficult to calculate the cash flow with a generic model. Because NIBC does not cover many LNG carriers in its portfolio, no data on prices, rates and Opex are known. The subscription at MSI is limited to the vessel types which are in the portfolio.

12

Update: changes to the implementation schedule of the BWM convention and the effects

The IMO Marine Environment Protection Committee (MEPC) approved draft amendments to the implementation schedule on the 7th of July 2017. This chapter will cover the changes and how shipowners will be effected.

12.1. Changes to the implementation schedule

As from the 7th of July 2017, the MEPC approved draft amendments to the implementation of the BWM convention. These draft amendments will be discussed after the 8th of September 2017 and are expected to be approved at the next MEPC session in April 2018.
The implementation date will still be on the 8th of September 2017. As from this date, all vessels will have to comply with the D-1 standard as discussed in chapter 1. This implies that the vessel should exchange at least 95% of the ballast water volume mid-ocean.
Keel-lays on or after the 8th of September 2017 will have to be in compliance with the D-2 standard. This implies that these vessels have to treat their ballast water before discharge.

The D-2 standard also applies for existing vessels having a first or second IOPP renewal after the 8th of September 2017:

- *By the first renewal survey: this applies when that the first renewal survey of the ship takes place on or after 8 September 2019 or a renewal survey has been completed on or after 8 September 2014 but prior to 8 September 2017.[**?**]*
- *By the second renewal survey: this applies if the first renewal survey after 8 September 2017 takes place before 8 September 2019. In this case, compliance must be by the second renewal survey (provided that the previous renewal survey has not been completed in the period between 8 September 2014 and 8 September 2017).[**?**]*

This implies that the D-2 standard has to be met at the first or second special survey after the 8th of September 2019, dependent on the previous special survey. An graphical overview of the new implementation schedule for vessels build before the 8th of September 2017 is shown in figure 12.1.

Chapter	Changes
Chapter 1	The implementation schedule changed
Chapter 8	Less vessels will have to install a BWT system as explained in section 12.2 from this chapter
Chapter 9	The impact on IRR will be slightly smaller and will concern less vessels
Chapter 10	The impact for NIBC will be smaller as the convention will concern less vessels

Table 12.1: Changes in every chapter due to the new implementation schedule

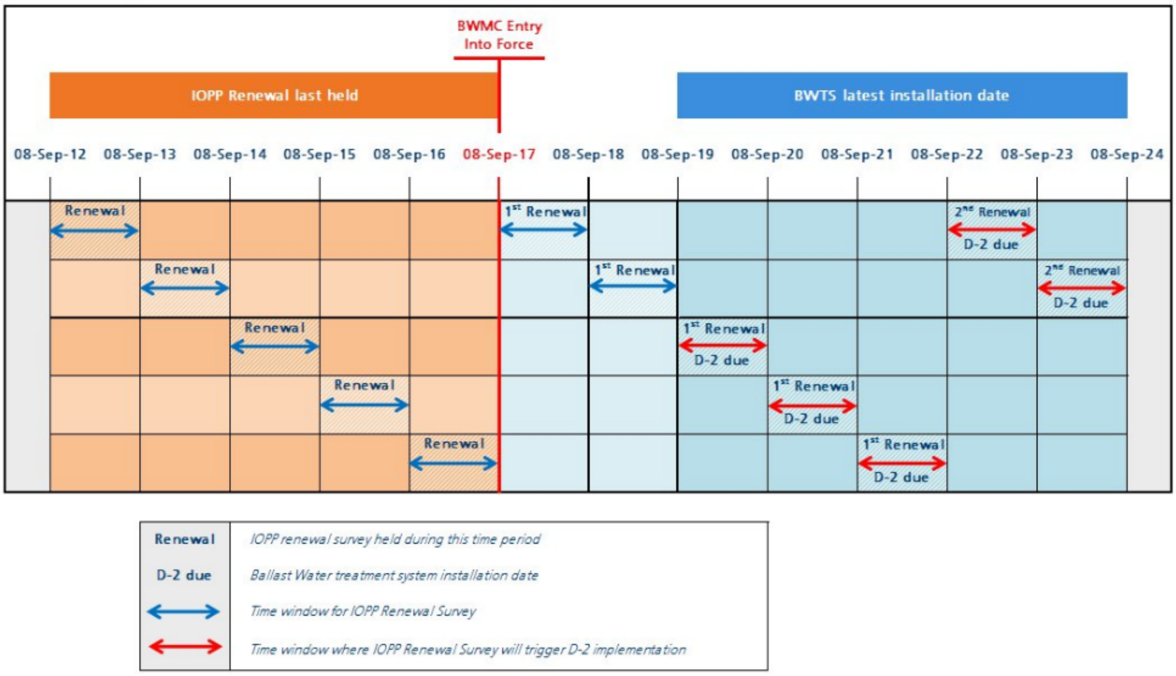
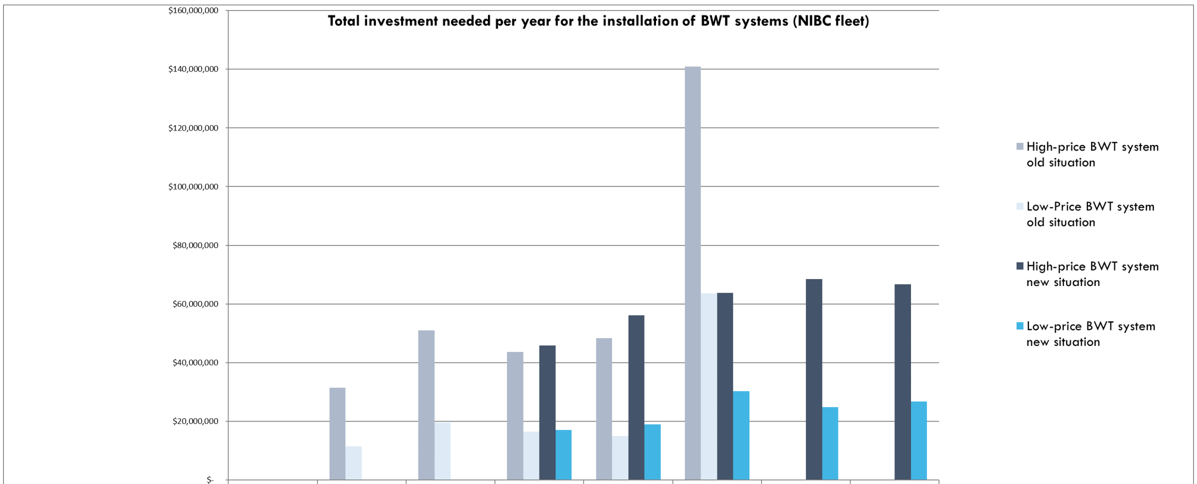


Figure 12.1: Graphical overview of the new implementation schedule for vessels built before 8-9-2017 [**?**]

Table 12.1 shows the chapters in this report that are effected by the change in implementation schedule. The changes and the effects are explained in this chapter.

12.2. Effects of the changes in the implementation schedule

The change in the implementation schedule only changes the strategies that perform an early IOPP renewal just before the implementation date. Some vessels will still benefit from an early IOPP renewal while others will wait for the regular special survey. This implies that the ability to postpone the installation date by renewing the IOPP before the 8th of September 2017 would only be beneficial for vessels with their planned renewal survey between September 2014 and September 2017. Vessels that have their renewal survey planned between September 2017 and September 2019 will not benefit from an early IOPP renewal. All the strategies that were discussed in this report remain the same and can all be applied.
The fact that it is not possible to perform an early IOPP renewal between the 8th of September 2017 and the 8th of September 2019 causes the spread of the installation dates to be more equal, as shown in figure 12.2. As some vessels still benefit from the IOPP renewal just before the 8th of September 2017 it is expected that there will be a slightly higher demand for BWT systems in 2022.



	IOPP renewal	2018	2019	2020	2021	2022	2023	2024
High-price BWT system old situation	$26,000	$31,474,635	$50,970,408	$43,638,609	$48,304,348	$140,969,701	$-	$-
Low-Price BWT system old situation	$26,000	$11,450,979	$19,557,698	$16,411,836	$15,047,124	$63,586,442	$-	$-
High-price BWT system new situation	$13,000	$-	$-	$45,783,280	$56,069,883	$63,745,800	$68,485,711	$66,721,983
Low-price BWT system new situation	$13,000	$-	$-	$16,996,195	$18,983,864	$30,258,315	$24,842,343	$26,809,800

Figure 12.2: Overview of the total investment cost needed for installing BWT systems on the vessels of NIBC's portfolio with the new implementation schedule.

	Old situation	New situation
Total investment needed for high-price BWT	$ 315,000,000	$ 301,000,000
Total investment needed for low-price BWT	$ 126,000,000	$ 118,000,000
Total vessel value	$ 4,930,000,000	$ 4,930,000,000
Total impact low-price BWT as a percentage of the vessel value	2.6	2.4 %
Total impact high-price BWT as a percentage of the vessel value	6.4	6.1 %

Table 12.2: Total investment cost and impact on the entire NIBC portfolio with the new implementation schedule

It can be seen from table 12.2 that the impact of the low-price BWT dropped from 2.6 % to 2.4 % and the high-price BWT impact dropped from 6.4 % to 6.1 %.

Due to the change in implementation schedule, the number of vessels that will have to install a ballast water treatment system will be lower for the existing fleet. Figure 12.3 shows the scenario's that should be followed for NIBC's portfolio. The smaller left pie chart shows the old situation whereas the larger right chart shows the outcome with the new implementation schedule. It can be seen that 10 more vessels do not have to install a BWT system as vessels built in September 2004 and before will not be impacted.

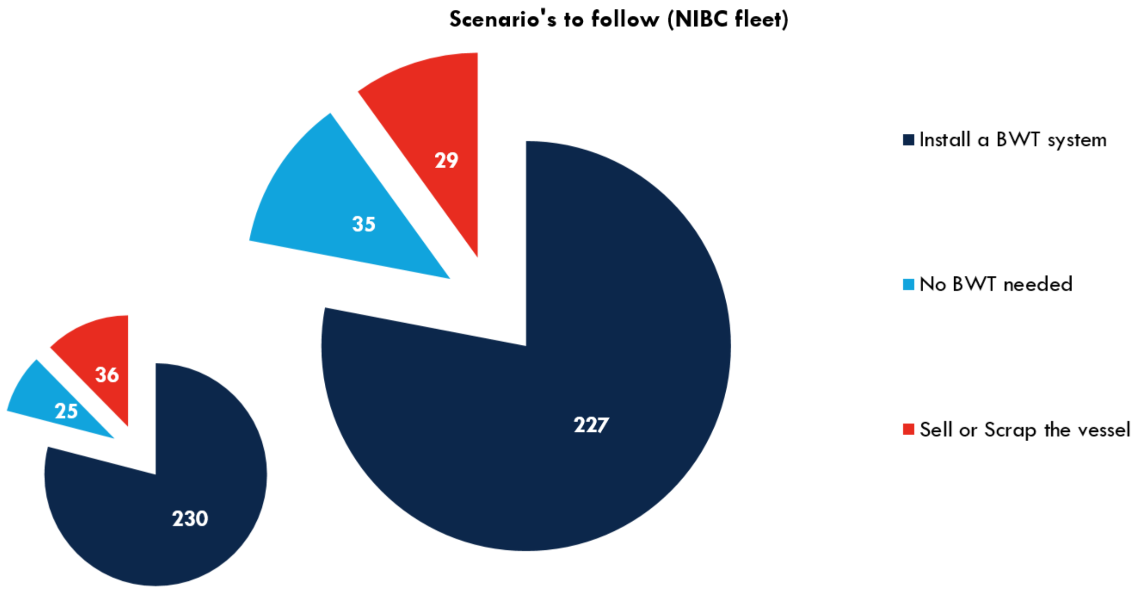


Figure 12.3: Scenario's to follow according to the tool. On the right the updated new situation and on the left, the old implementation schedule.

By analysing the outcome of the tool for all vessel types an impact for younger and older vessels can be made just as with the old implementation schedule. This is shown in figure 12.4. Note that the older vessels are more in advance because part of these vessels will not be impacted at all.

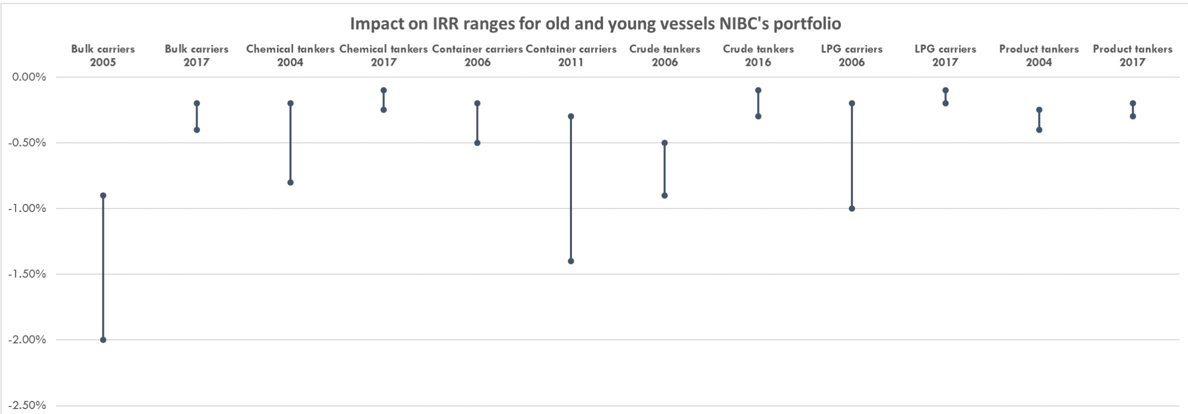


Figure 12.4: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of NIBC's portfolio in the new situation.

The all the graphs as shown in chapter 9 about the impact on IRR and the possible IRR for each vessel type can be found in appendix F. An overview of the difference and comparison between the old and the new implementation schedule is shown in table 12.3.

Drydock	Old situation	New situation	Difference in outcome
2012	regular renewal in 2017	regular renewal in 2017	No difference
2013	early IOPP renewal in 2017	regular renewal in 2018	1 year of advantage
2014	early IOPP renewal in 2017	regular renewal in 2019 (before 7th of Sept)	2 years of advantage
2015	early IOPP renewal in 2017	early IOPP renewal in 2017 (before 8th of Sept)	No difference
2016	early IOPP renewal in 2017	early IOPP renewal in 2017 (before 8th of Sept)	No difference
New build	Install when built after 7-9-2017	Install when built after 7-9-2017	No difference

Table 12.3: Overview of the comparison between the new and old implementation schedule

Abbreviations

Abbreviation	**Description**
ABS	American Bureau of Shipping
AMS	Alternate Management System
APT	Aft Peak Tank
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosibles
BWDS	Ballast Water Discharge Standard
BWT	Ballast Water Treatment
BWTS	Ballast Water Treatment System
BWM	Ballast Water management
CBD	Convention on Biological Diversity
cfu	Colony forming unit
CIP	Cleaning In Place
DBT	Double Bottom Tank
DWT	Dead Weight Tonnage
EC	Electro Chlorination
FPSO	Floating Production, Storage and Offloading vessel
FPT	Fore Peak Tank
FSU	Floating Storage Unit
GLD	Gas Lift Diffusing
GT	Gross Tonnage
HSSC	Harmonized System of Survey and Certification
IAS	Invasive Aquatic Species
IEC	Import Export Code
IFO 180	Intermediate fuel oil with a maximum viscosity of 180 centistokes
IGG	Inert Gas Generator
IMO	International Maritime Organisation
IOPP	International Oil Pollution Prevention certificate
IRR	Internal Rate of Return
LIBOR	London Interbank Offered Rate
LOA	Length Over All
LPG	Liquefied Petroleum Gas
LPS	Lamp Power Supply
LTV	Loan to value
MEPC	Marine Environment Protection Committee
NIBC	Nationale Investerings Bank Corporate
NPV	Net Present Value
OBS	Optimarin Ballast System
Opex	Operating expenditure
pH	Potential Hydrogen
PSU	Practical Salinity Unit
RFR	Required Freight Rate
Ro-Ro	Roll on - Roll off
SCR	Selective Catalytic Reduction
SFOC	Specific Fuel Oil Consumption
SRA	Same Risk Area
SRB	Sulfate Reducing Bacteria
T/C	Time Charter
TEU	Twenty-foot Equivalent Unit
TST	Top Side Tank
US	United States
USCG	United States Coast Guard
USD	United States Dollar
UV	Ultra Violet
UVT	Ultra Violet Transmittance

Appendices

Appendix A

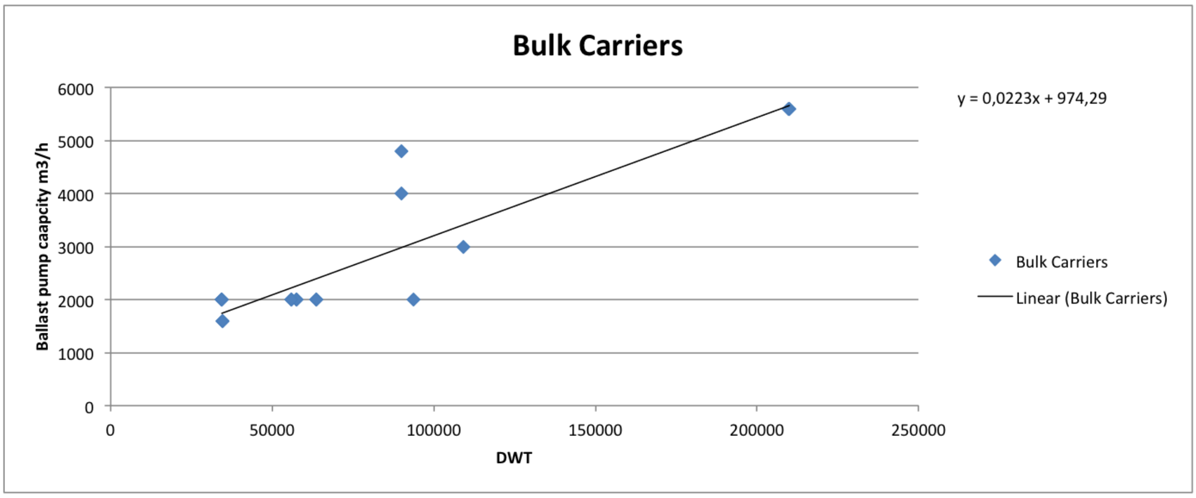


Figure A.1: Correlation between DWT and ballast water pump capacity m3/h [?] [?] [?] [?].

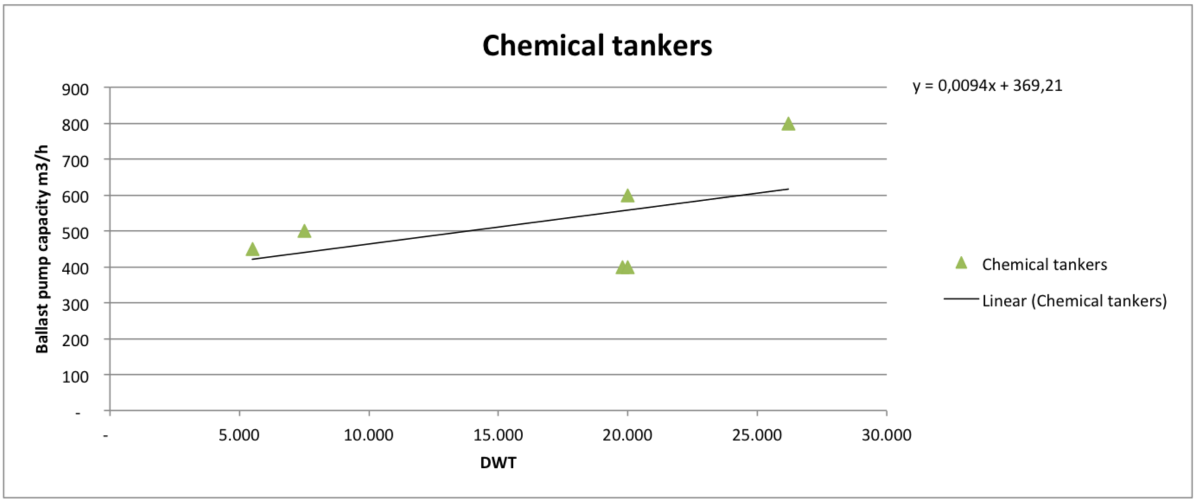


Figure A.2: Correlation between DWT and ballast water pump capacity m3/h [?] [?] [?] [?].

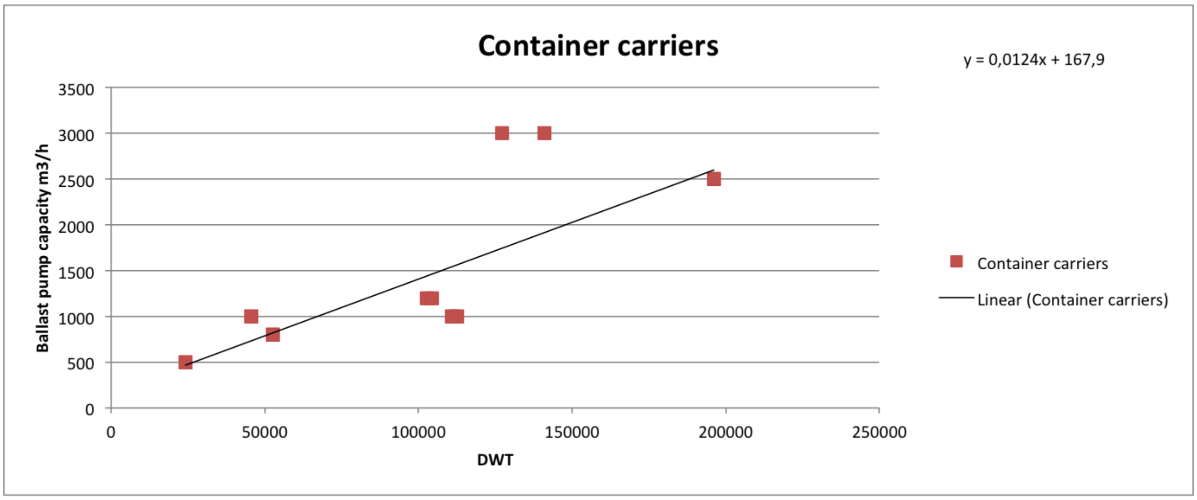


Figure A.3: Correlation between DWT and ballast water pump capacity m3/h [?] [?] [?] [?].

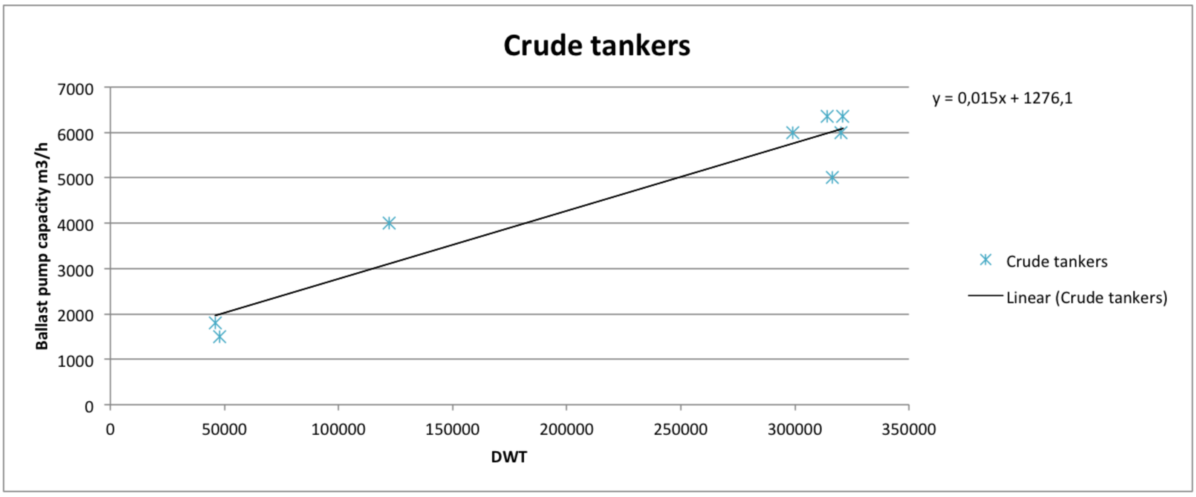


Figure A.4: Correlation between DWT and ballast water pump capacity m3/h [?] [?] [?] [?].

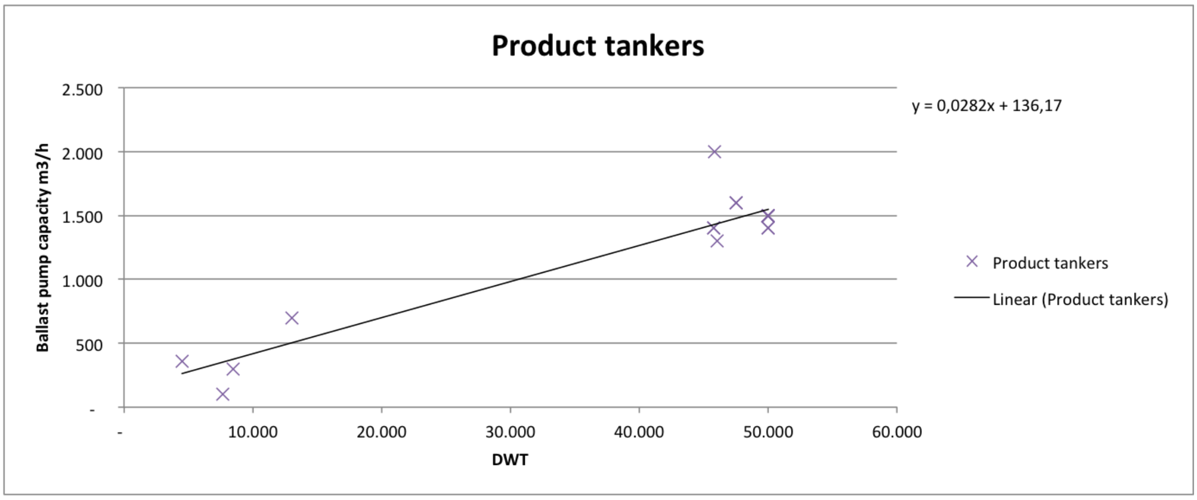


Figure A.5: Correlation between DWT and ballast water pump capacity m3/h [?] [?] [?] [?].

B

Appendix B

Brand	Method	capacity	Footprint per m3/h	Difference %
Alfa laval UV	UV	300	0,002	0%
Techcross EC	EC	450	0,002	10%
Techcross EC	EC	150	0,002	23%
Techcross EC	EC	300	0,003	37%
Hyde marine	UV	300	0,004	110%
Hyde marine	UV	250	0,005	146%
Hyde marine	UV	500	0,005	171%
Hyde marine	UV	450	0,006	201%
Optimarin	UV	500	0,007	247%
Hyde marine	UV	150	0,008	285%
Optimarin	UV	334	0,008	322%
Hyde marine	UV	60	0,010	418%
Hyde marine	UV	100	0,011	472%
Optimarin	UV	167	0,014	590%
Wärtsila UV	UV	500	0,017	751%
Wärtsila UV	UV	430	0,020	911%
Wärtsila UV	UV	300	0,021	970%
Wärtsila UV	UV	375	0,023	1049%
Wärtsila UV	UV	250	0,026	1184%
Wärtsila UV	UV	180	0,032	1523%
Wärtsila UV	UV	125	0,037	1754%
Wärtsila UV	UV	80	0,055	2676%
Wärtsila UV	UV	50	0,075	3666%

Table B.1: Footprint for 50 - 500 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	rank
Techcross EC	EC	150	0,092	0%
Techcross EC	EC	300	0,092	0%
Techcross EC	EC	450	0,092	0%
DESMI	UV	300	0,147	59%
DESMI	UV	500	0,176	91%
Hyde marine	UV	150	0,200	117%
Hyde marine	UV	250	0,200	117%
Hyde marine	UV	500	0,200	117%
Alfa laval UV	UV	300	0,213	132%
DESMI	UV	200	0,220	139%
DESMI	UV	400	0,220	139%
Hyde marine	UV	450	0,222	142%
Hyde marine	UV	300	0,227	146%
Hyde marine	UV	100	0,300	226%
Hyde marine	UV	60	0,333	262%
Optimarin	UV	167	0,419	356%
Optimarin	UV	334	0,419	356%
Optimarin	UV	500	0,420	357%
DESMI	UV	100	0,440	378%
Wärtsila UV	UV	430	0,479	421%
Wärtsila UV	UV	500	0,501	444%
Wärtsila UV	UV	375	0,505	448%
Wärtsila UV	UV	125	0,608	561%
Wärtsila UV	UV	300	0,636	591%
Wärtsila UV	UV	250	0,642	597%
Wärtsila UV	UV	180	0,858	832%
Wärtsila UV	UV	80	0,950	933%
Wärtsila UV	UV	50	1,520	1552%

Table B.2: Power consumption for 50 - 500 m3/h ballast water treatment systems.

Brand	Method	capacity	Footprint per m3/h	Difference %
Alfa laval UV	UV	1000	0,001	0%
Alfa laval UV	UV	600	0,002	4%
Techcross EC	EC	600	0,002	37%
Techcross EC	EC	1000	0,002	40%
Hyde marine	UV	1000	0,004	193%
Hyde marine	UV	600	0,004	204%
Optimarin	UV	1000	0,005	268%
Optimarin	UV	834	0,005	270%
Hyde marine	UV	700	0,006	280%
Optimarin	UV	667	0,006	320%
Wärtsila UV	UV	1000	0,016	997%
Wärtsila UV	UV	550	0,017	1047%
Wärtsila UV	UV	850	0,018	1151%
Wärtsila UV	UV	750	0,021	1318%
Wärtsila EC	EC	1000	0,043	2807%
Wärtsila EC	EC	850	0,046	3030%
Wärtsila EC	EC	750	0,052	3448%

Table B.3: Footprint for 501 - 1000 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	Difference %
Wärtsila EC	EC	750	0,081	0%
Wärtsila EC	EC	850	0,084	3%
Wärtsila EC	EC	1000	0,086	6%
Techcross EC	EC	600	0,092	13%
Techcross EC	EC	1000	0,092	13%
DESMI	UV	600	0,147	80%
DESMI	UV	900	0,147	80%
Hyde marine	UV	1000	0,150	84%
DESMI	UV	800	0,165	103%
Hyde marine	UV	600	0,167	105%
DESMI	UV	1000	0,176	116%
DESMI	UV	700	0,189	132%
Alfa laval UV	UV	1000	0,200	146%
Alfa laval UV	UV	600	0,210	158%
Hyde marine	UV	700	0,214	163%
Wärtsila UV	UV	1000	0,400	392%
Optimarin	UV	834	0,420	416%
Optimarin	UV	667	0,420	416%
Optimarin	UV	1000	0,420	416%
Wärtsila UV	UV	850	0,471	479%
Wärtsila UV	UV	750	0,492	505%
Wärtsila UV	UV	550	0,678	733%

Table B.4: Power consumption for 501 - 1000 m3/h ballast water treatment systems.

Brand	Method	capacity	Footprint per m3/h	Difference %
Hyde marine	UV	1500	0,003	0%
Hyde marine	UV	1250	0,004	20%
Optimarin	UV	1334	0,005	50%
Optimarin	UV	1500	0,005	52%
Optimarin	UV	1167	0,005	60%
Alfa laval UV	UV	1500	0,008	147%
Wärtsila EC	EC	1500	0,025	676%
Wärtsila EC	EC	1200	0,038	1095%

Table B.5: Footprint for 1001 - 1500 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	Difference %
Wärtsila EC	EC	1500	0,082	0%
Wärtsila EC	EC	1200	0,093	13%
DESMI	UV	1200	0,147	79%
DESMI	UV	1500	0,147	79%
Hyde marine	UV	1500	0,152	85%
DESMI	UV	1400	0,157	92%
DESMI	UV	1100	0,160	95%
DESMI	UV	1300	0,169	106%
Hyde marine	UV	1250	0,182	122%
Alfa laval UV	UV	1500	0,267	225%
Optimarin	UV	1334	0,420	412%
Optimarin	UV	1167	0,420	412%
Optimarin	UV	1500	0,420	412%

Table B.6: Power consumption for 1001 - 1500 m3/h ballast water treatment systems.

Brand	Method	capacity	Footprint per m3/h	Difference %
Techcross EC	EC	2000	0,002	0%
Optimarin	UV	2000	0,004	112%
Hyde marine	UV	2000	0,004	115%
Optimarin	UV	1834	0,005	120%
Optimarin	UV	1667	0,005	129%
Alfa laval UV	UV	2000	0,006	186%
ColdHarbour	Inert gas	1600	0,008	280%
Wärtsila UV	UV	2000	0,016	683%
Wärtsila EC	EC	2000	0,021	898%

Table B.7: Footprint for 1501 - 2000 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	Difference %
Wärtsila EC	EC	2000	0,084	0%
Techcross EC	EC	2000	0,092	10%
DESMI	UV	1800	0,147	75%
Hyde marine	UV	2000	0,150	79%
DESMI	UV	2000	0,154	83%
DESMI	UV	1700	0,155	85%
DESMI	UV	1900	0,162	93%
ColdHarbour	Inert gas	1600	0,163	93%
DESMI	UV	1600	0,165	96%
Alfa laval UV	UV	2000	0,200	138%
Wärtsila UV	UV	2000	0,400	376%
Optimarin	UV	1834	0,420	400%
Optimarin	UV	1667	0,420	400%
Optimarin	UV	2000	0,420	400%

Table B.8: Power consumption for 1501 - 2000 m3/h ballast water treatment systems.

Brand	Method	capacity	Footprint per m3/h	Difference %
Techcross EC	EC	3000	0,002	0%
ColdHarbour	Inert gas	2400	0,002	11%
Hyde marine	UV	3000	0,003	57%
Hyde marine	UV	2500	0,004	89%
Optimarin	UV	2500	0,004	103%
Optimarin	UV	2334	0,004	109%
Optimarin	UV	3000	0,004	109%
Optimarin	UV	2834	0,004	114%
Optimarin	UV	2167	0,004	115%
Optimarin	UV	2667	0,005	120%
ColdHarbour	Inert gas	2400	0,006	174%
Alfa laval UV	UV	3000	0,013	543%
Wärtsila UV	UV	3000	0,016	683%
Wärtsila EC	EC	3000	0,016	697%
Wärtsila EC	EC	2400	0,019	832%

Table B.9: Footprint for 2001 - 3000 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	Difference %
Wärtsila EC	EC	3000	0,088	0%
Wärtsila EC	EC	2400	0,090	2%
Techcross EC	EC	3000	0,092	4%
ColdHarbour	Inert gas	2400	0,108	23%
ColdHarbour	Inert gas	2400	0,108	23%
DESMI	UV	2100	0,147	66%
DESMI	UV	2400	0,147	66%
DESMI	UV	2700	0,147	66%
DESMI	UV	3000	0,147	66%
DESMI	UV	2900	0,152	72%
Hyde marine	UV	3000	0,152	72%
DESMI	UV	2600	0,152	72%
DESMI	UV	2300	0,153	73%
DESMI	UV	2800	0,157	78%
DESMI	UV	2500	0,158	79%
DESMI	UV	2200	0,160	81%
Hyde marine	UV	2500	0,182	106%
Alfa laval UV	UV	3000	0,200	126%
Wärtsila UV	UV	3000	0,400	353%
Optimarin	UV	2334	0,420	375%
Optimarin	UV	2834	0,420	375%
Optimarin	UV	2167	0,420	375%
Optimarin	UV	2667	0,420	375%
Optimarin	UV	2500	0,420	375%
Optimarin	UV	3000	0,420	375%

Table B.10: Power consumption for 2001 - 3000 m3/h ballast water treatment systems.

Brand	Method	capacity	Footprint per m3/h	Difference %
ColdHarbour	Inert gas	5000	0,002	0%
ColdHarbour	Inert gas	5400	0,002	5%
ColdHarbour	Inert gas	6000	0,002	6%
ColdHarbour	Inert gas	7200	0,002	6%
ColdHarbour	Inert gas	6400	0,002	9%
ColdHarbour	Inert gas	3400	0,002	27%
Techcross EC	EC	4000	0,002	37%
Techcross EC	EC	5000	0,002	37%
Techcross EC	EC	6000	0,002	37%
ColdHarbour	Inert gas	6000	0,003	83%
ColdHarbour	Inert gas	5600	0,003	85%
ColdHarbour	Inert gas	5000	0,003	93%
Hyde marine	UV	6000	0,003	108%
Hyde marine	UV	5000	0,004	149%
Hyde marine	UV	4000	0,005	214%
Wärtsila EC	UV	3300	0,015	889%

Table B.11: Footprint for 3001 - 6400 m3/h ballast water treatment systems.

Brand	Method	capacity	kWh/m3	Difference %
ColdHarbour	Inert gas	6400	0,052	0%
ColdHarbour	Inert gas	6000	0,055	7%
ColdHarbour	Inert gas	5400	0,057	11%
ColdHarbour	Inert gas	5600	0,059	14%
ColdHarbour	Inert gas	5000	0,062	20%
ColdHarbour	Inert gas	5000	0,062	20%
ColdHarbour	Inert gas	7200	0,066	27%
ColdHarbour	Inert gas	3400	0,076	47%
ColdHarbour	Inert gas	6000	0,079	52%
Techcross EC	EC	4000	0,092	77%
Techcross EC	EC	5000	0,092	77%
Techcross EC	EC	6000	0,092	77%
Wärtsila EC	UV	3300	0,097	87%
Hyde marine	UV	4000	0,150	189%
Hyde marine	UV	6000	0,152	193%
Hyde marine	UV	5000	0,182	252%

Table B.12: Power consumption for 3001 - 6400 m3/h ballast water treatment systems.

C

Appendix C

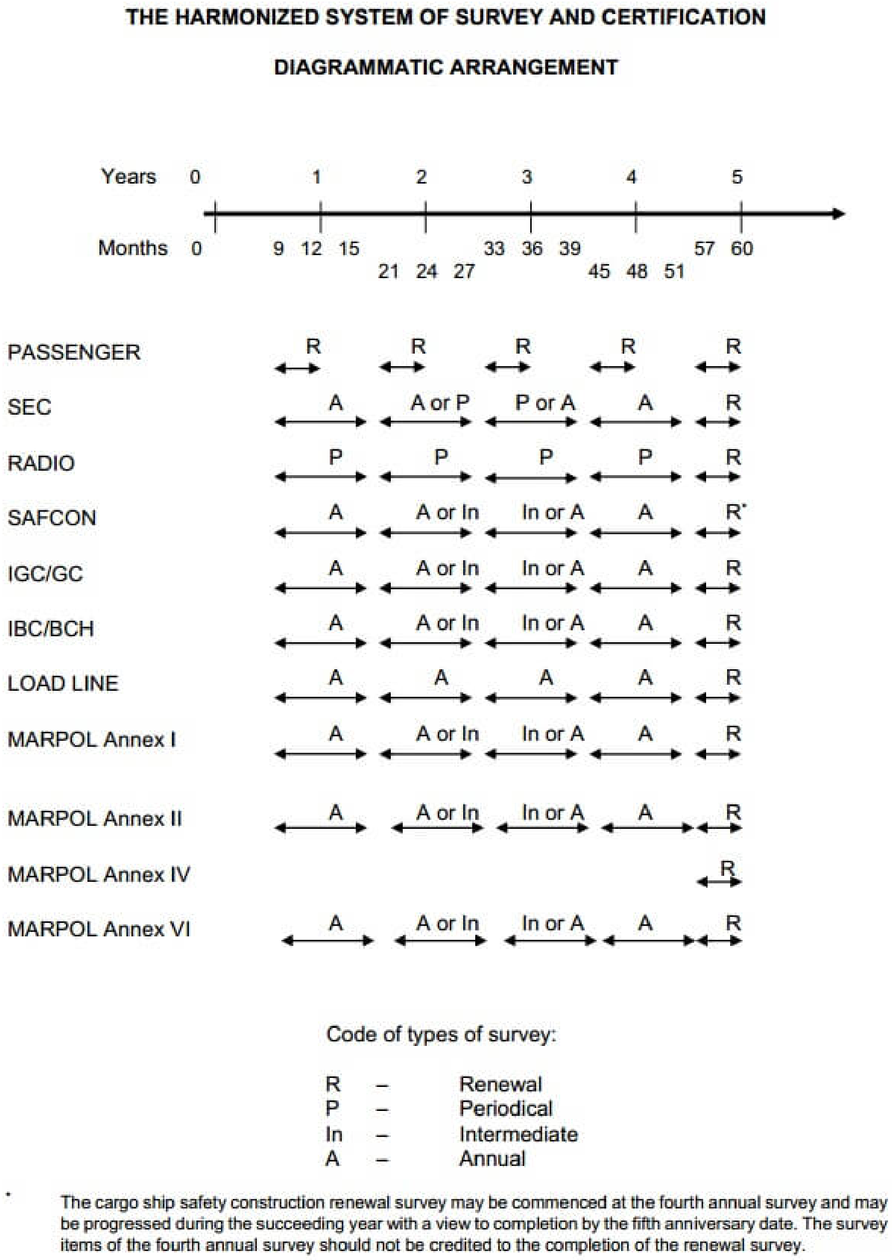


Figure C.1: Renewal survey scheme.

Appendix D

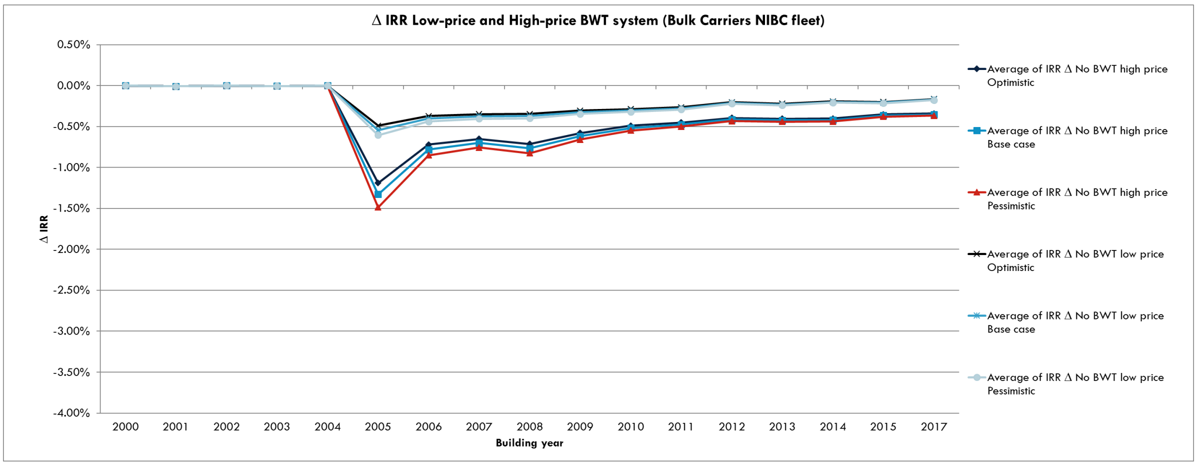


Figure D.1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of bulk carriers when the implementation date is set at 7/9/2019.

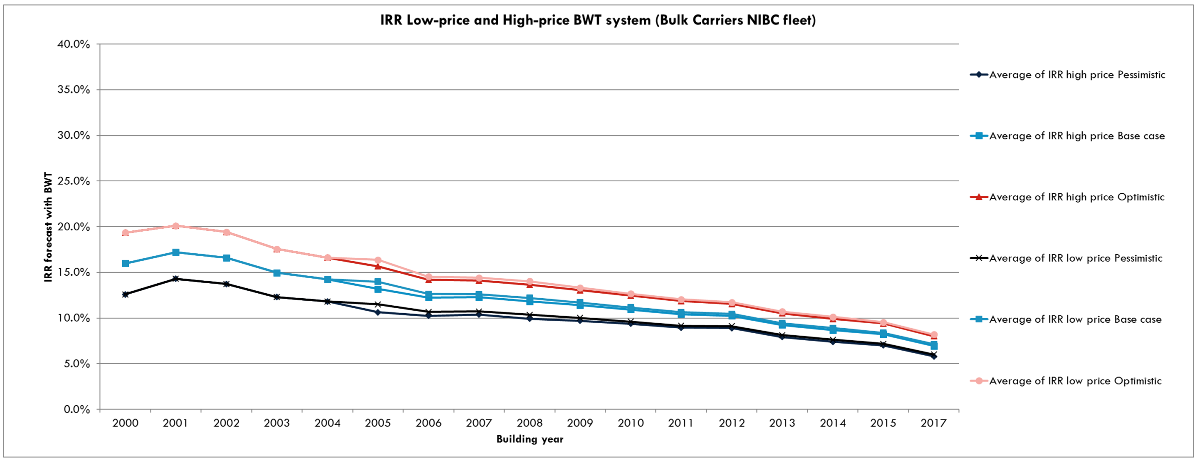


Figure D.2: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of bulk carriers when the implementation date is set at 7/9/2019.

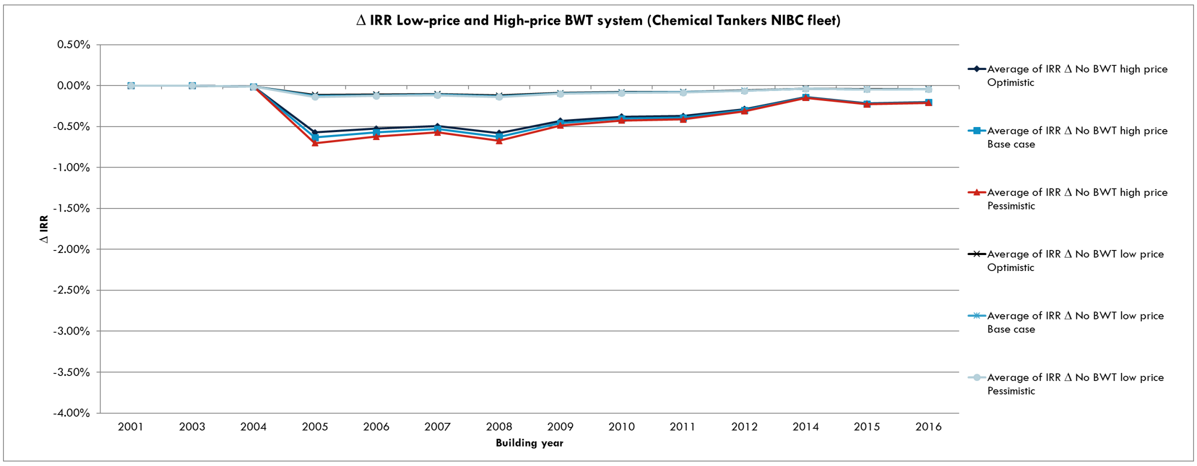


Figure D.3: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of chemical tankers when the implementation date is set at 7/9/2019.

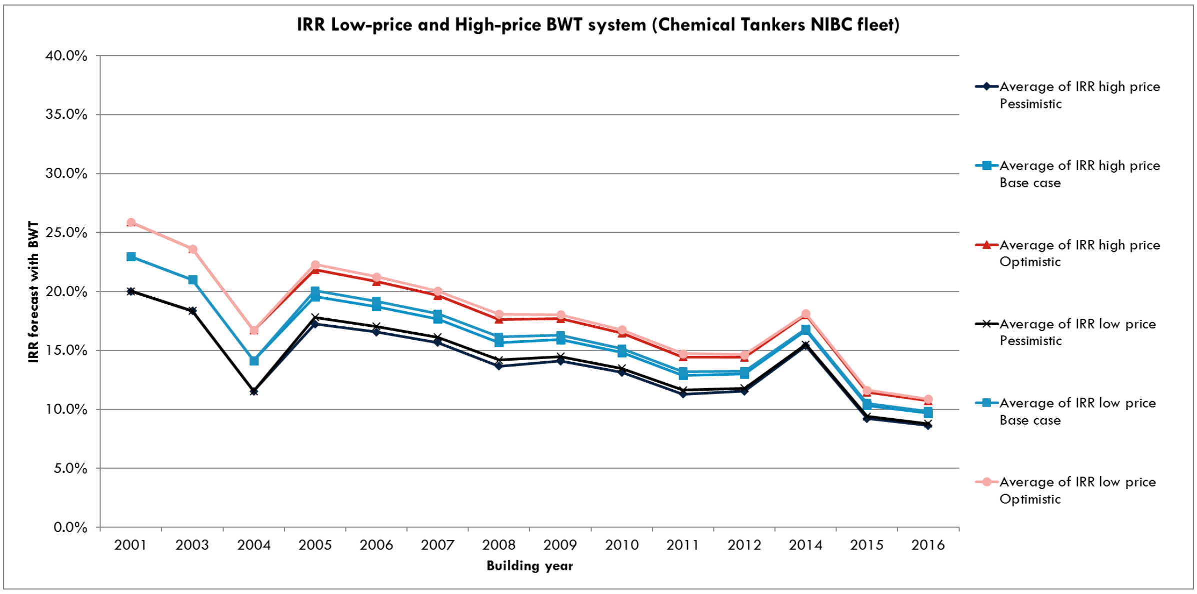


Figure D.4: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of chemical tankers when the implementation date is set at 7/9/2019.

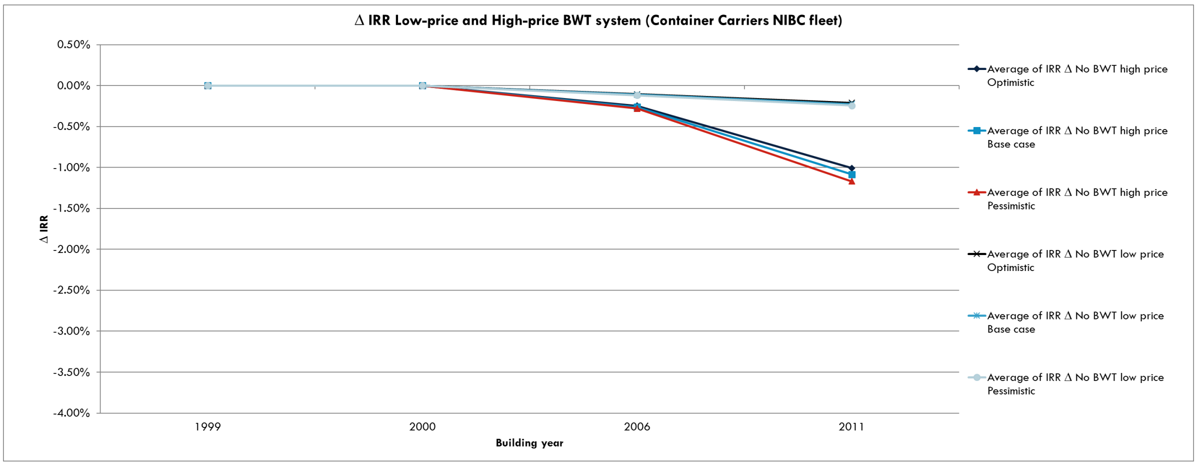


Figure D.5: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of container carriers when the implementation date is set at 7/9/2019.

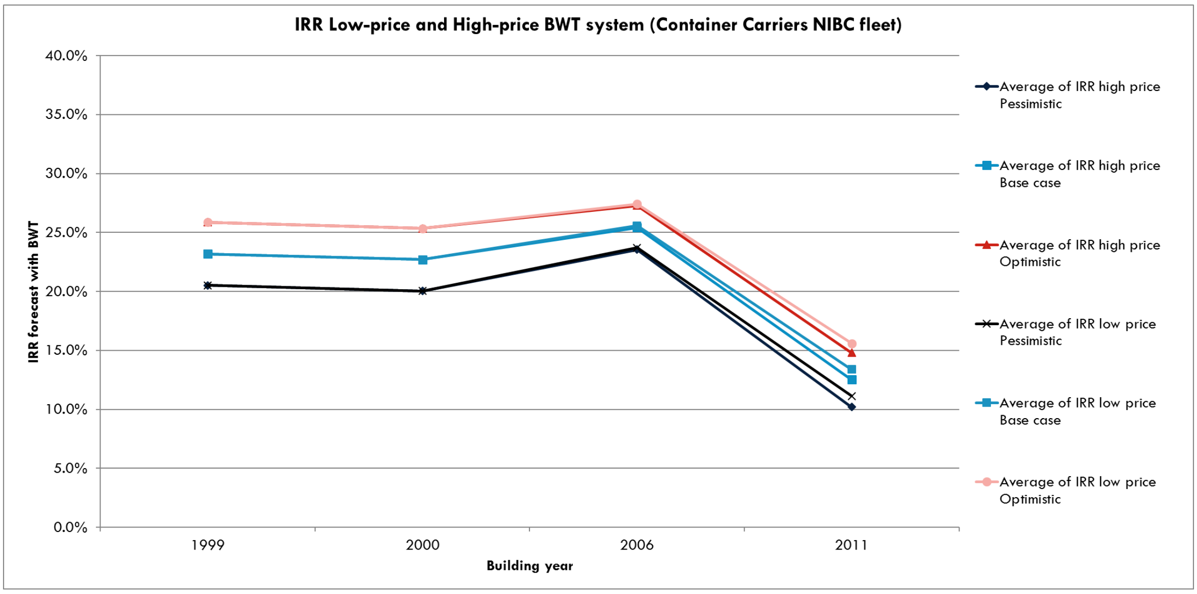


Figure D.6: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of container carriers when the implementation date is set at 7/9/2019.

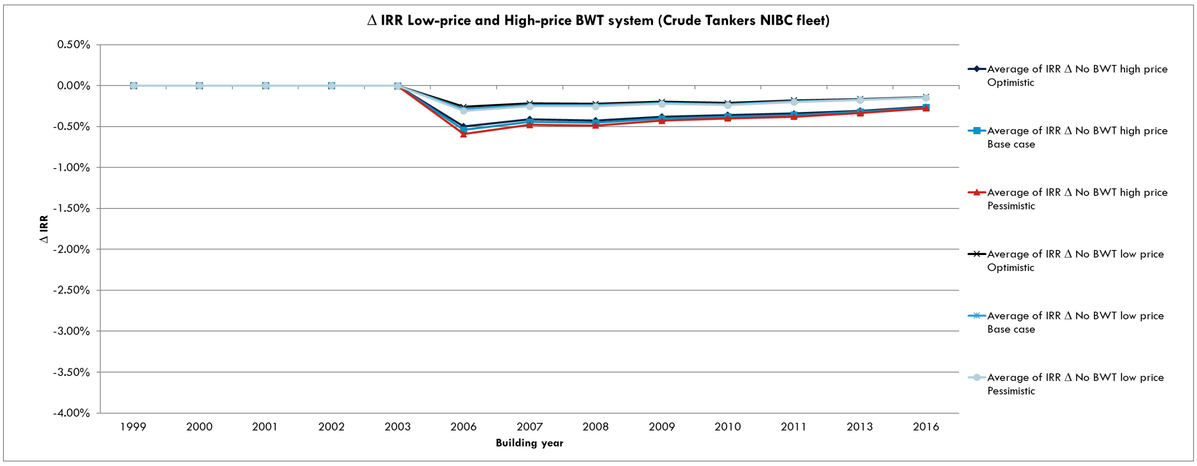


Figure D.7: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of crude tankers when the implementation date is set at 7/9/2019.

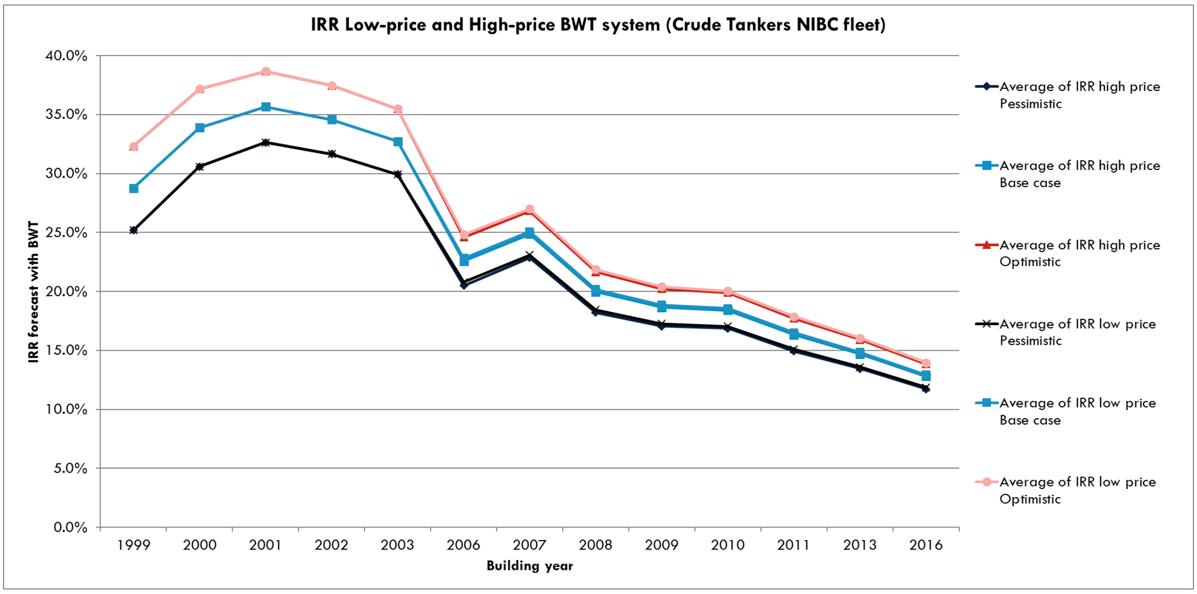


Figure D.8: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of crude tankers when the implementation date is set at 7/9/2019.

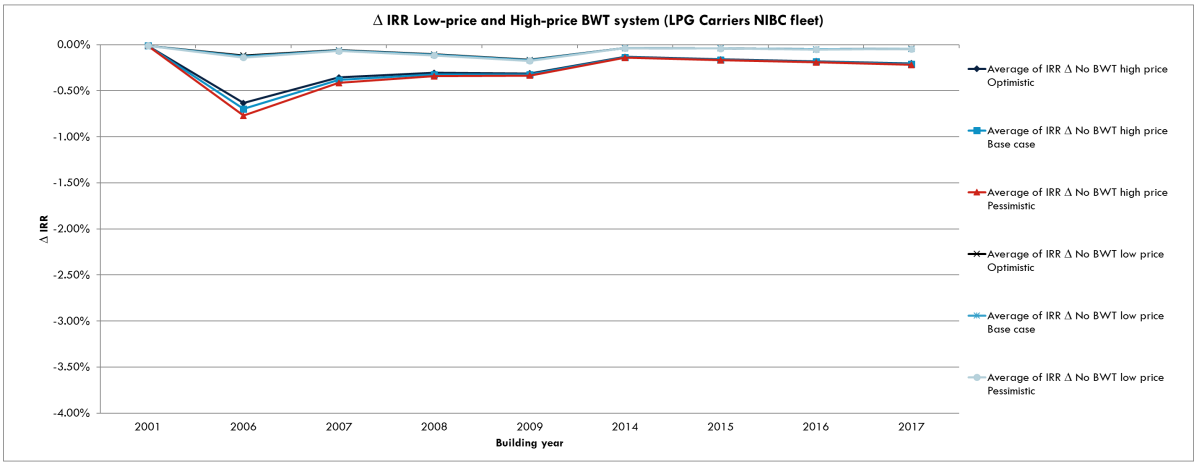


Figure D.9: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of LPG carriers when the implementation date is set at 7/9/2019.

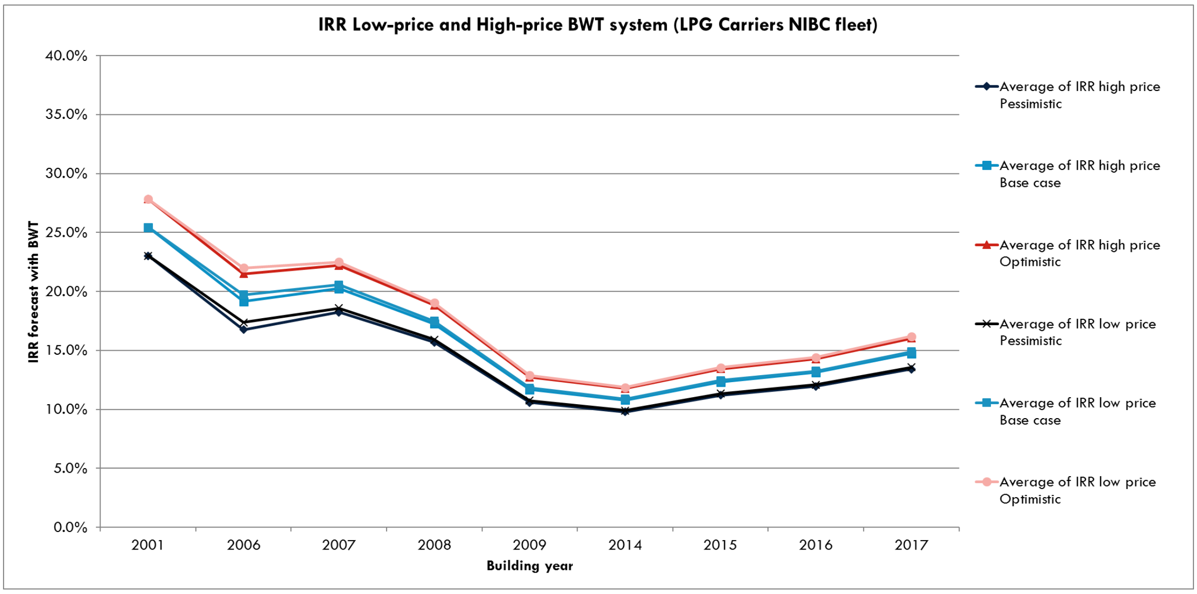


Figure D.10: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of LPG carriers when the implementation date is set at 7/9/2019.

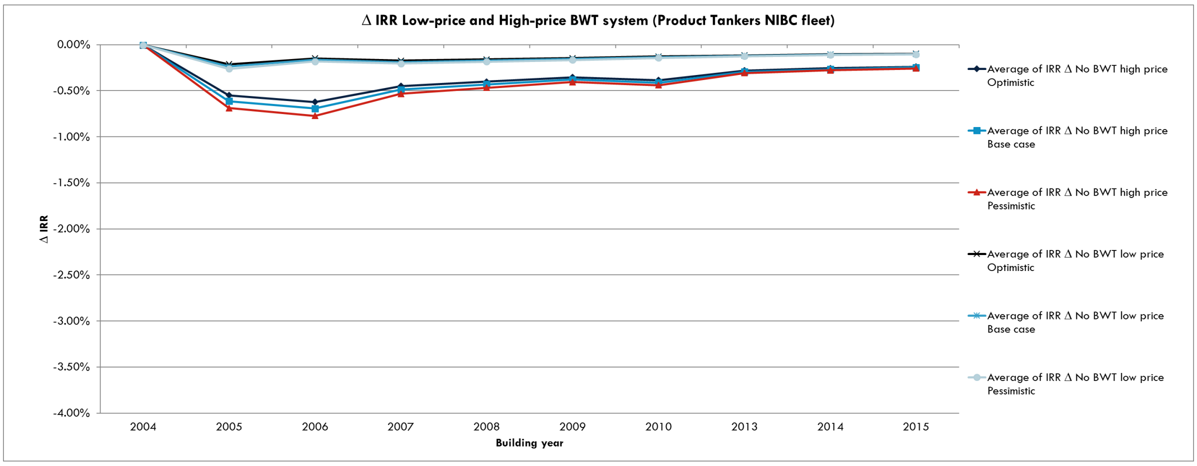


Figure D.11: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of product tankers when the implementation date is set at 7/9/2019.

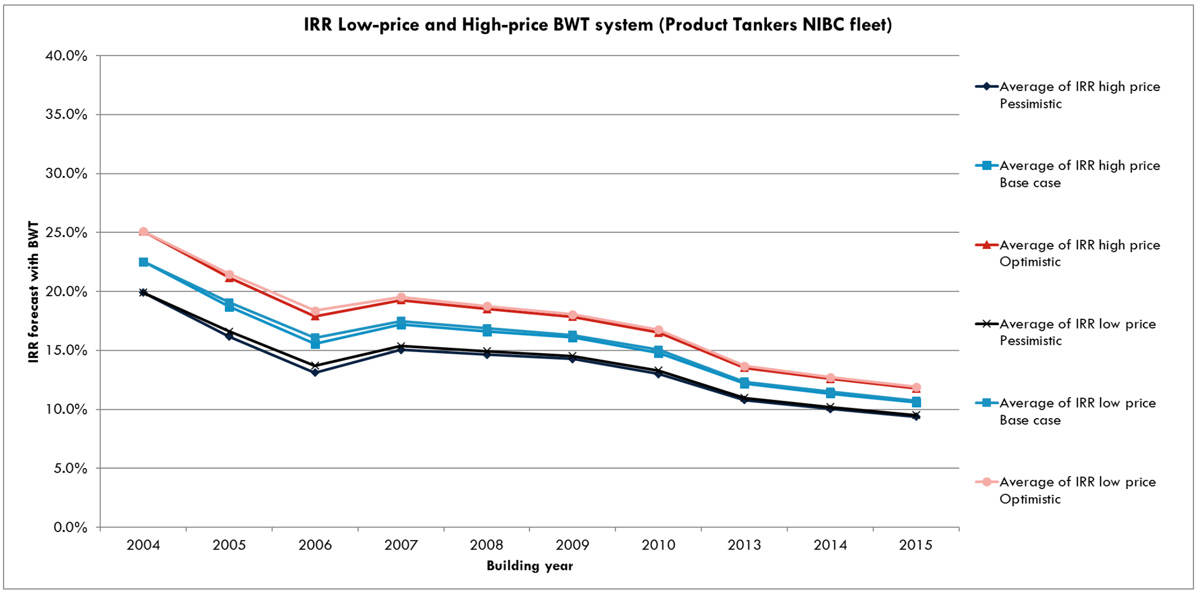


Figure D.12: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of product tankers when the implementation date is set at 7/9/2019.

E

Appendix E

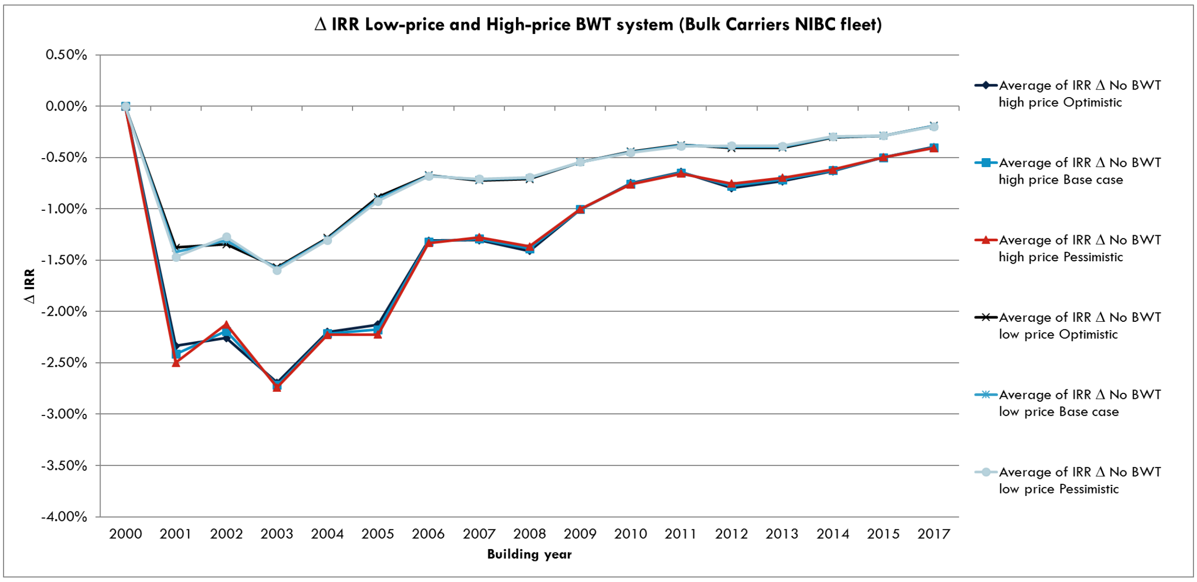


Figure E.1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of bulk carriers when all vessels have to comply with USCG regulation.

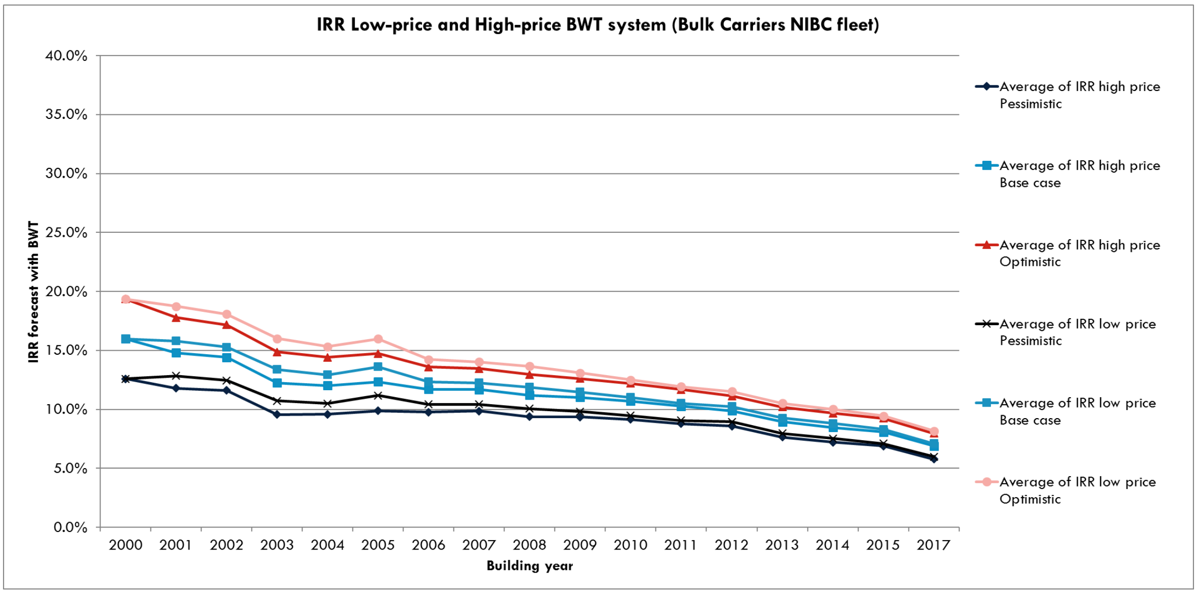


Figure E.2: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of bulk carriers when all vessels have to comply with USCG regulation.

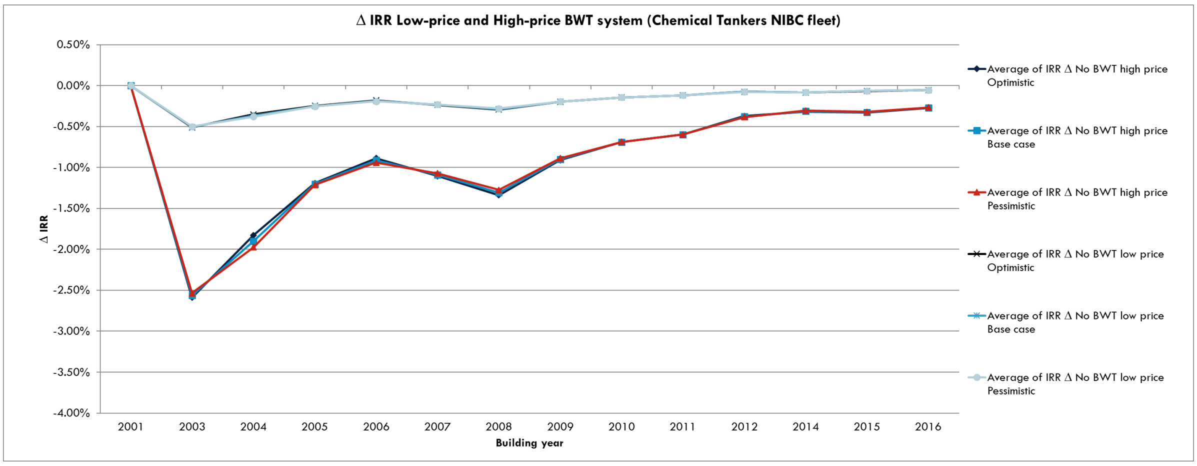


Figure E.3: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of chemical tankers when all vessels have to comply with USCG regulation.

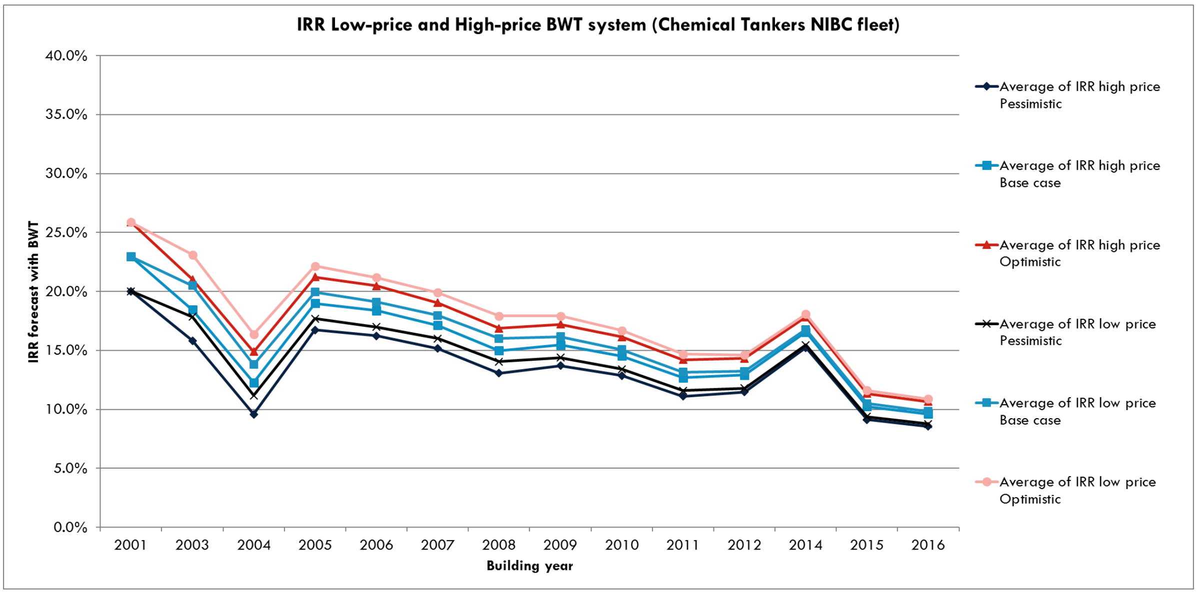


Figure E.4: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of chemical tankers when all vessels have to comply with USCG regulation.

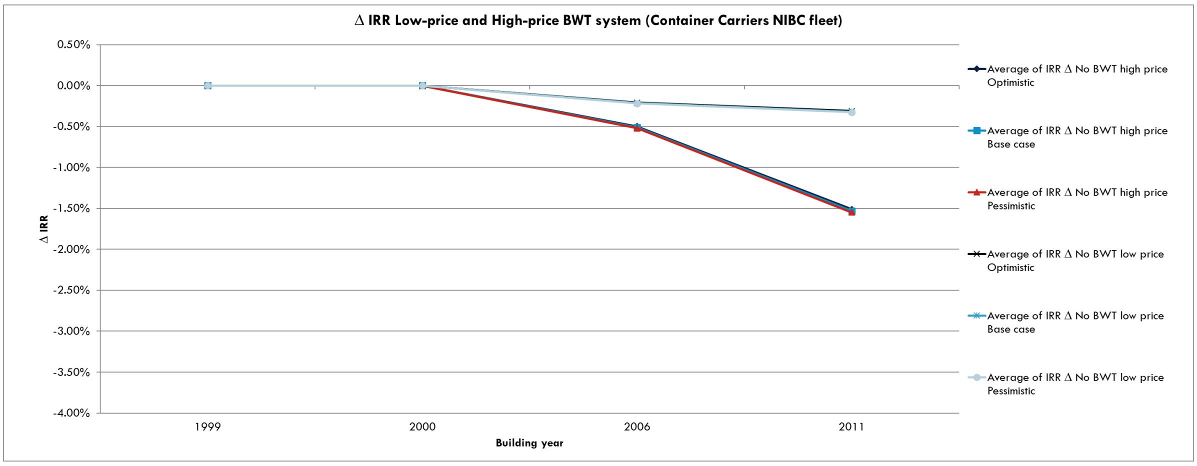


Figure E.5: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of container carriers when all vessels have to comply with USCG regulation.

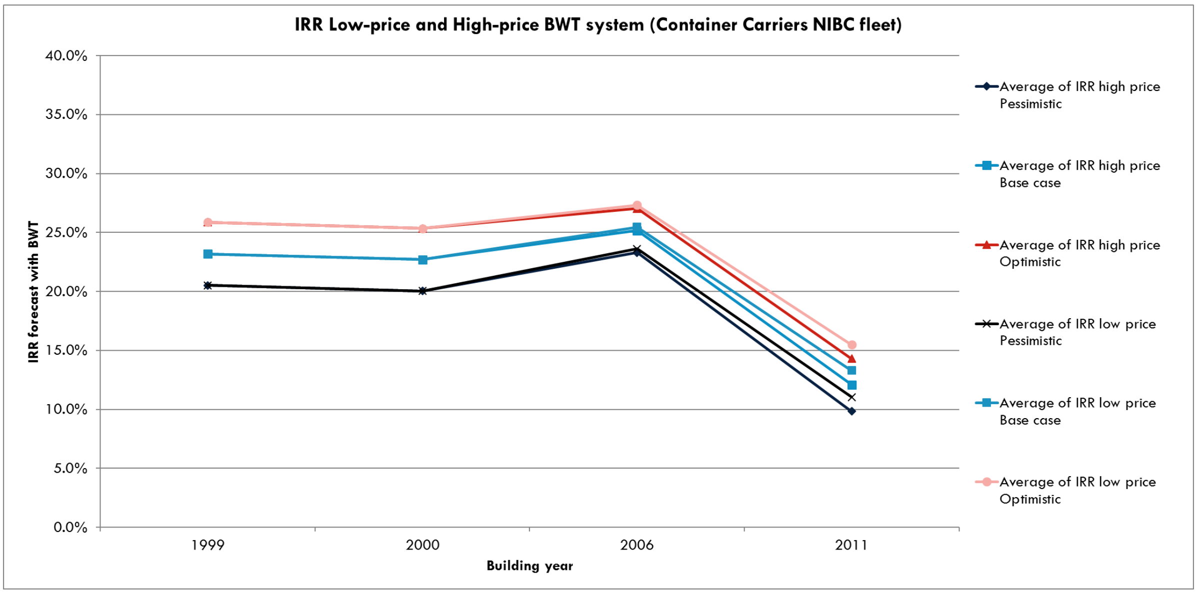


Figure E.6: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of container carriers when all vessels have to comply with USCG regulation.

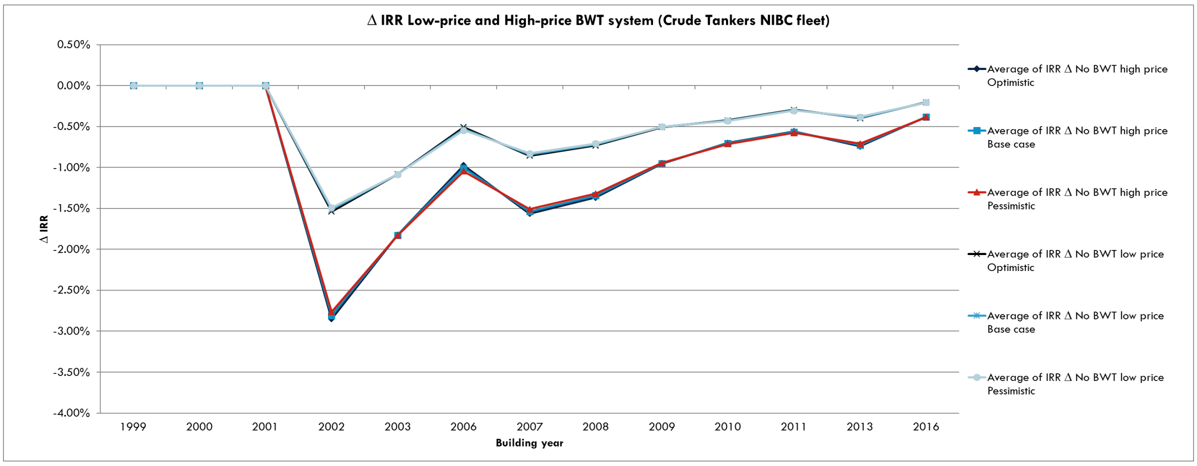


Figure E.7: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of crude tankers when all vessels have to comply with USCG regulation.

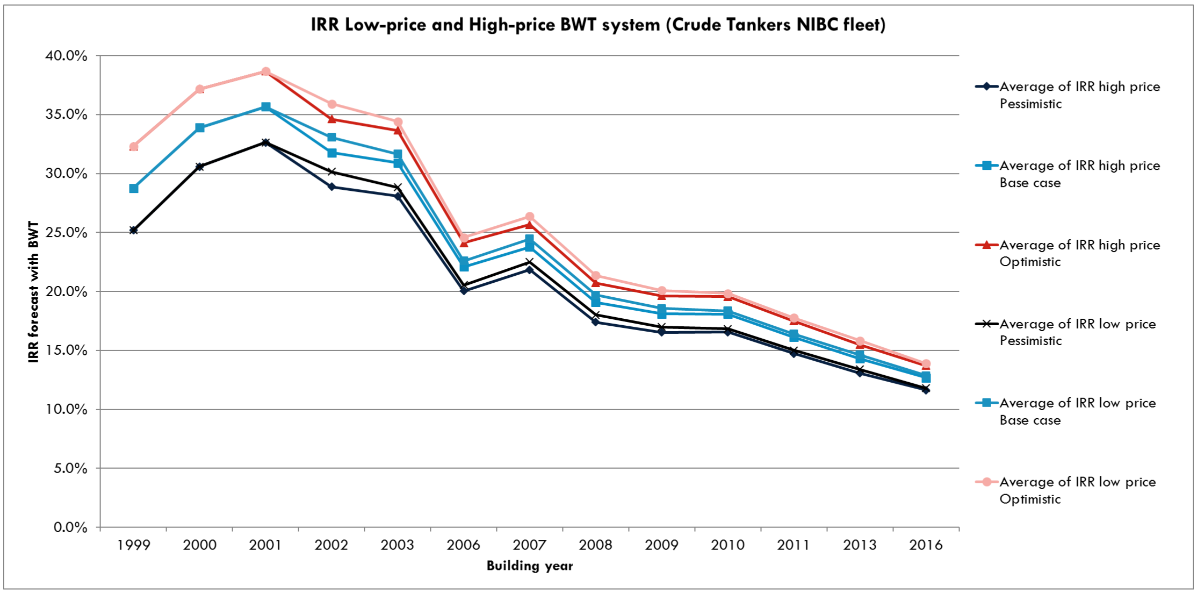


Figure E.8: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of crude tankers when all vessels have to comply with USCG regulation.

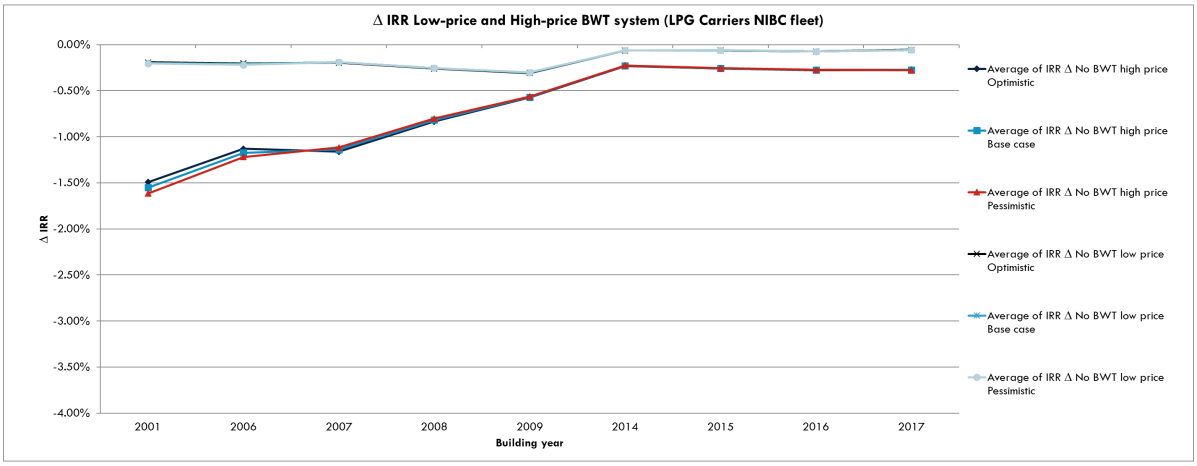


Figure E.9: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of LPG carriers when all vessels have to comply with USCG regulation.

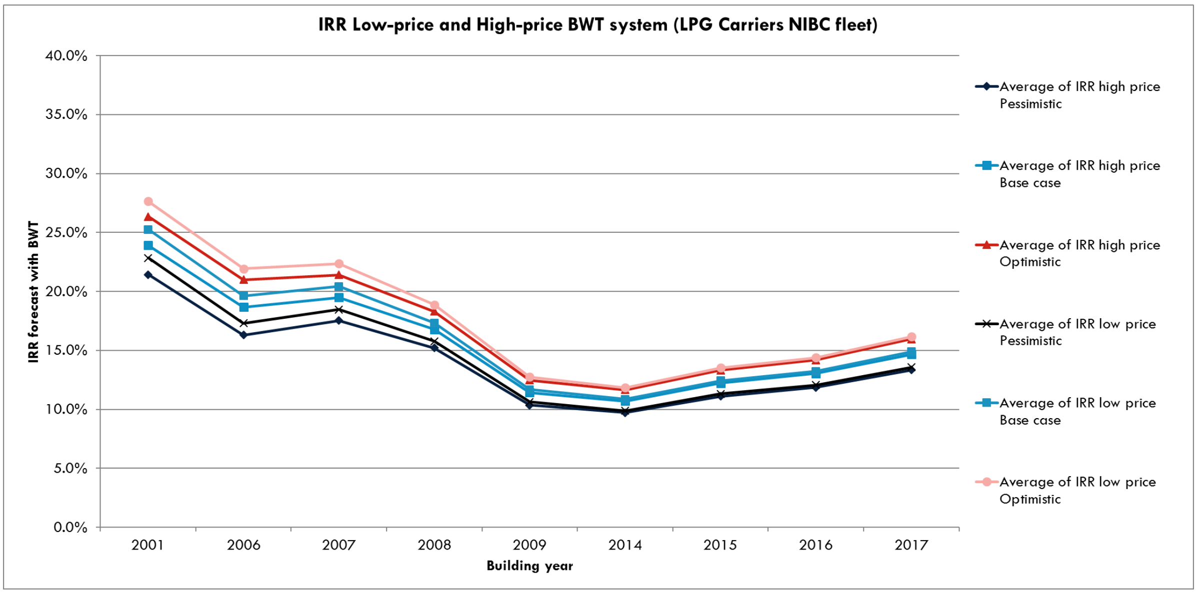


Figure E.10: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of LPG carriers when all vessels have to comply with USCG regulation.

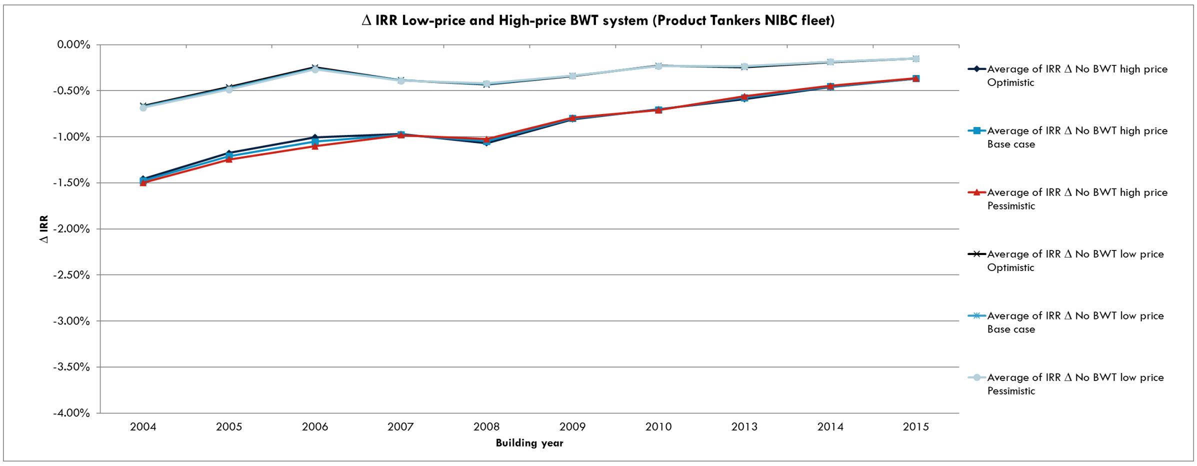


Figure E.11: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of product tankers when all vessels have to comply with USCG regulation.

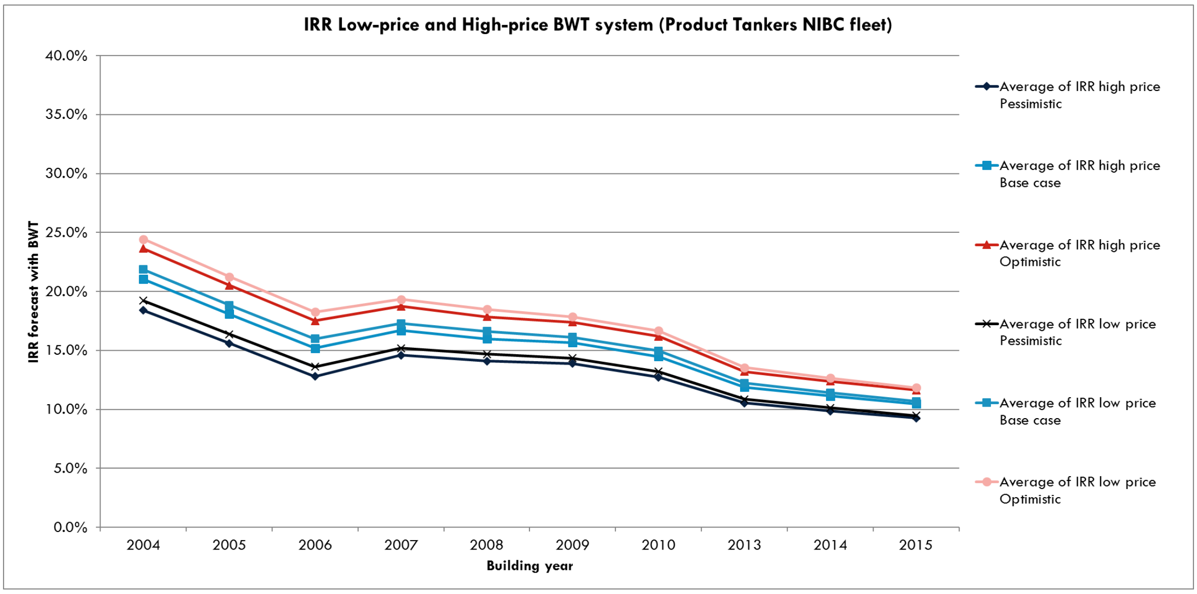


Figure E.12: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of product tankers when all vessels have to comply with USCG regulation.

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Appendix F

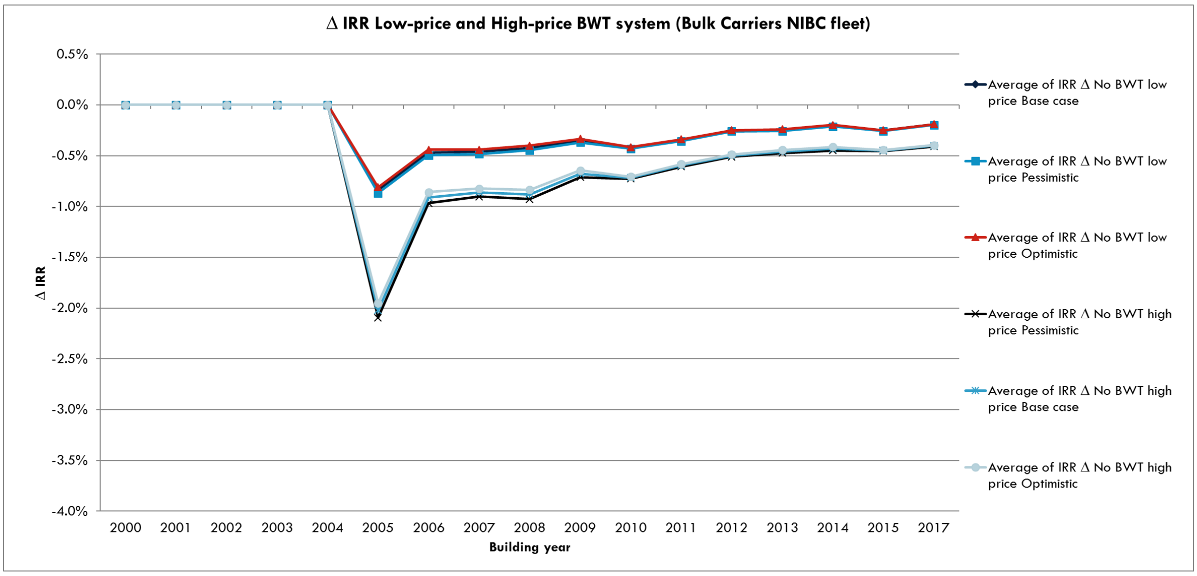

Figure F.1: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of bulk carriers with the updated implementation schedule.

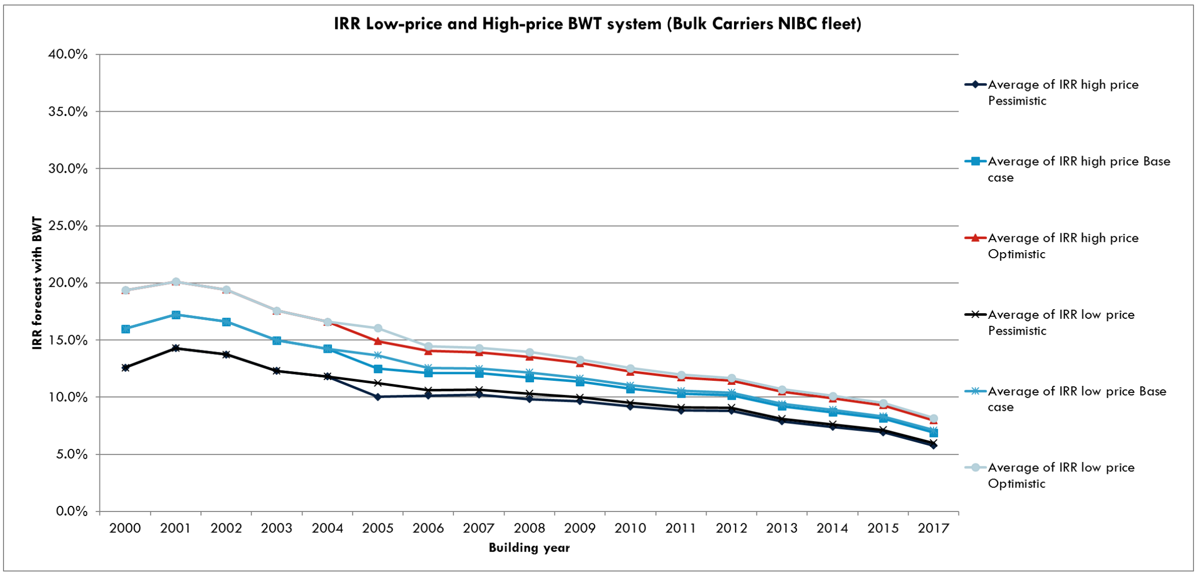

Figure F.2: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of bulk carriers with the updated implementation schedule.

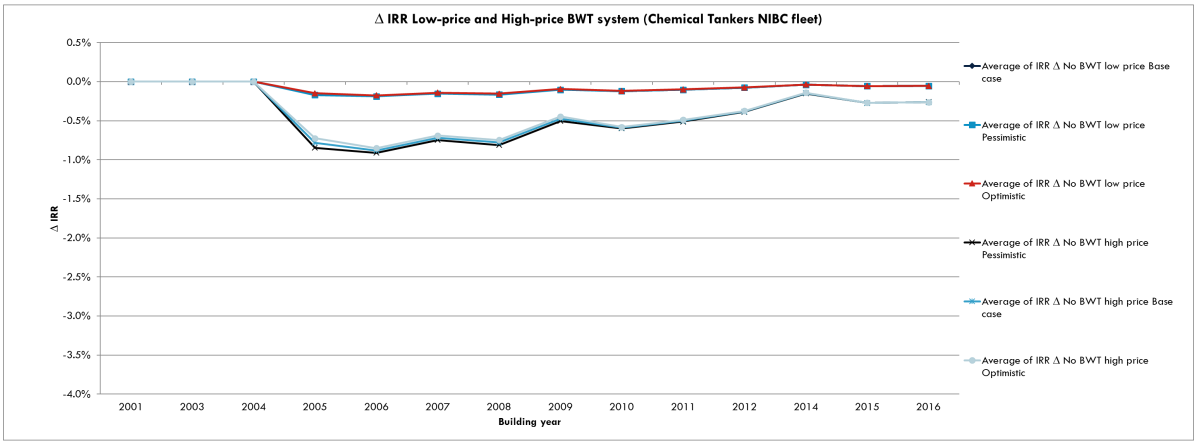

Figure F.3: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of chemical tankers with the updated implementation schedule.

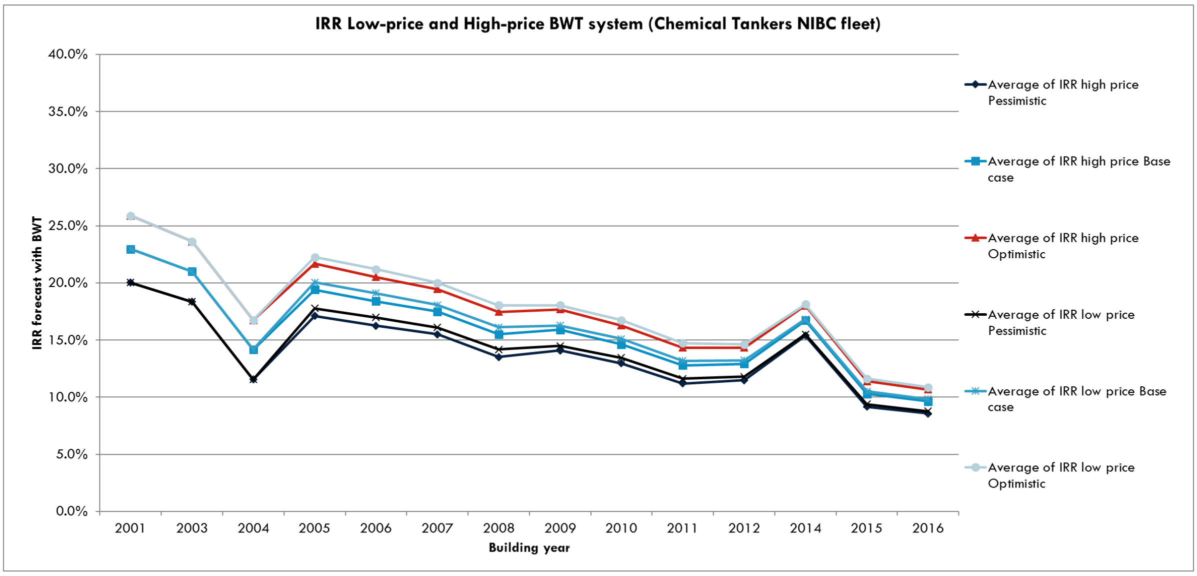

Figure F.4: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of chemical tankers with the updated implementation schedule.

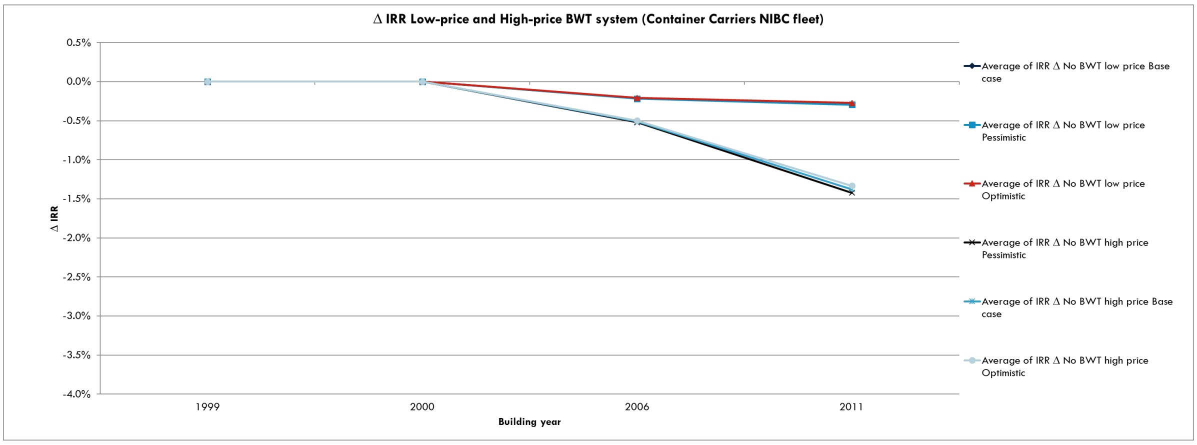

Figure F.5: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of container carriers with the updated implementation schedule.

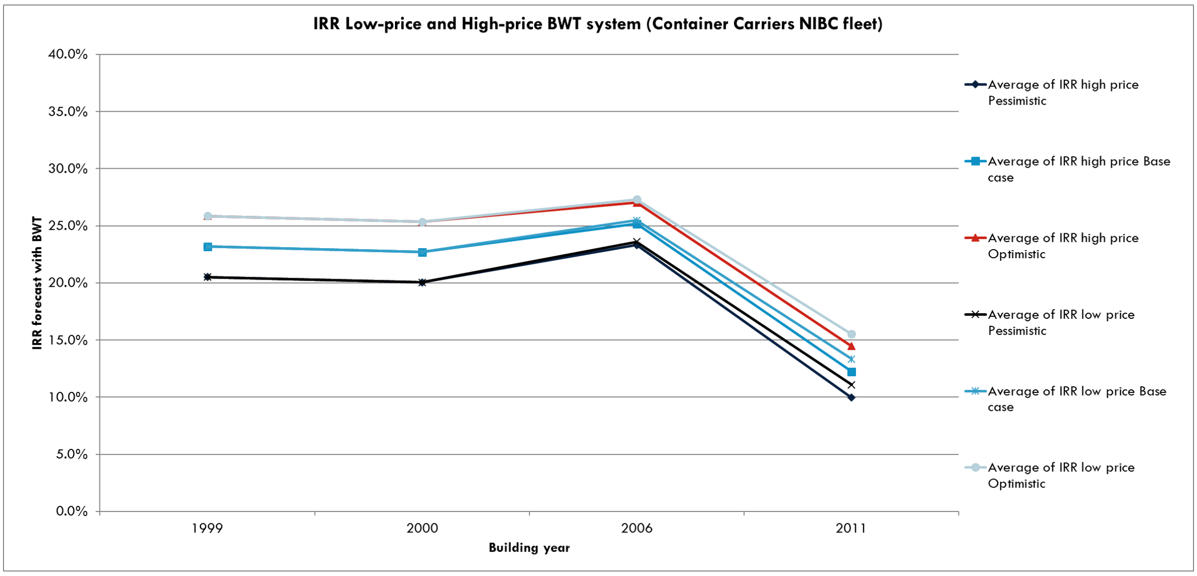

Figure F.6: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of container carriers with the updated implementation schedule.

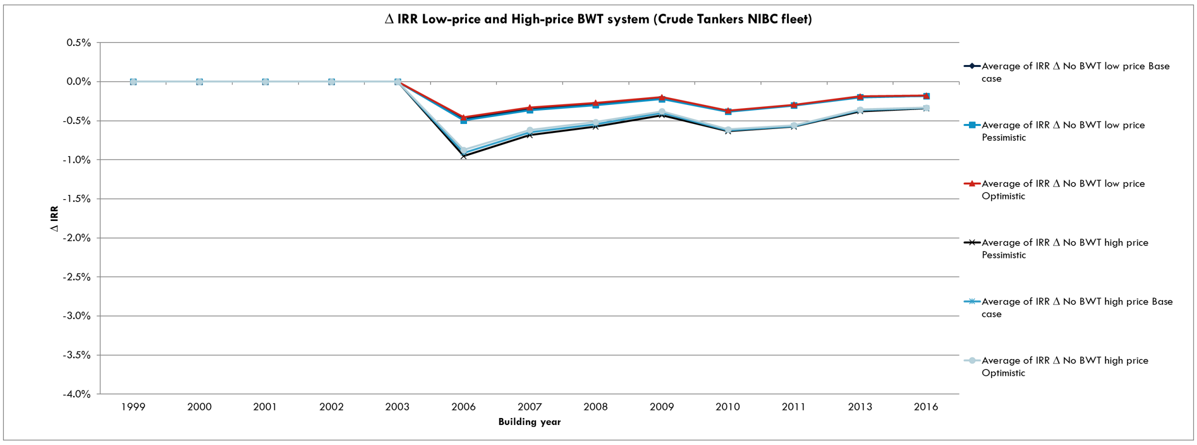

Figure F.7: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of crude tankers with the updated implementation schedule.

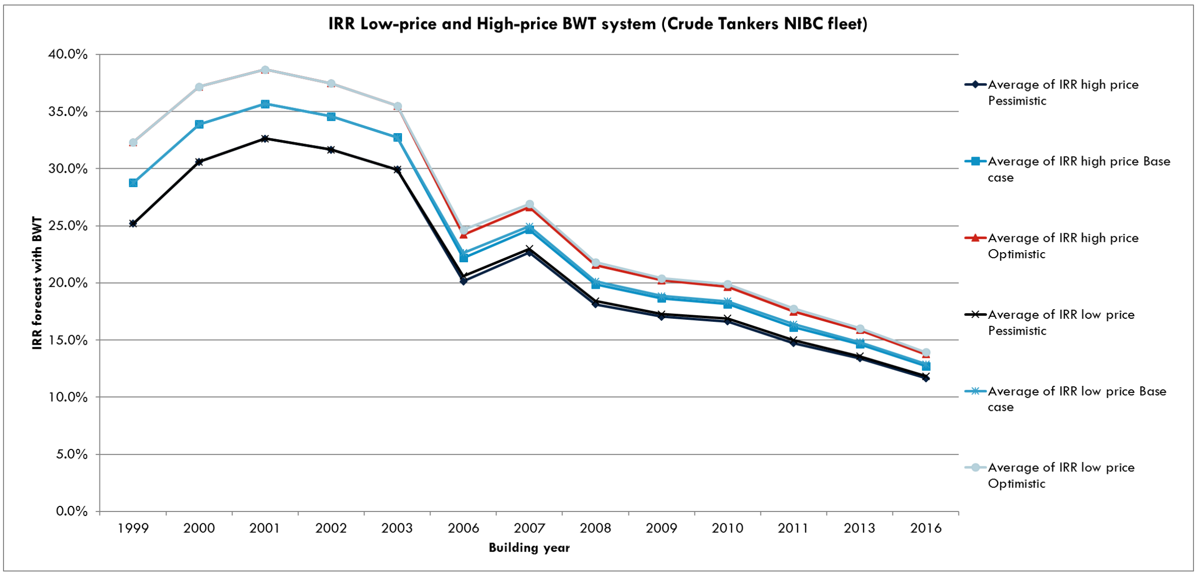

Figure F.8: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of crude tankers with the updated implementation schedule.

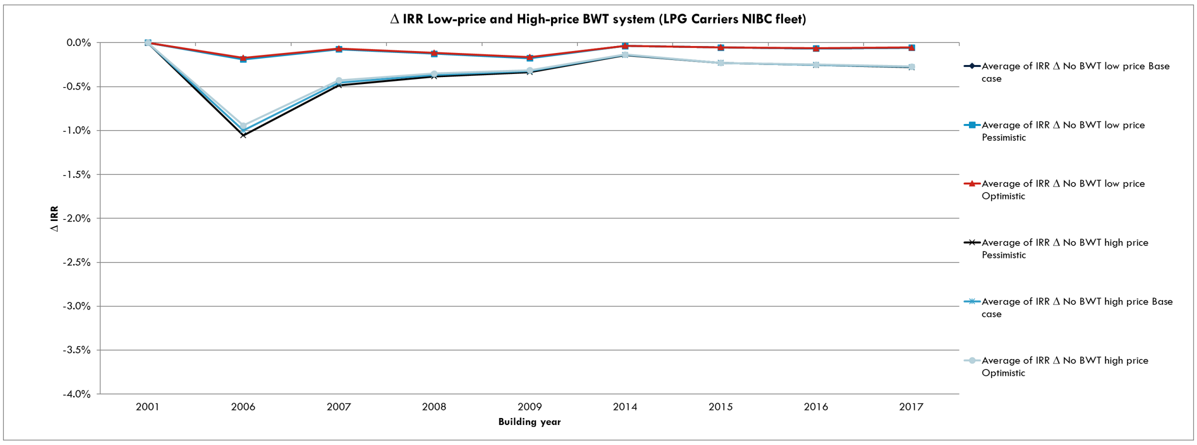

Figure F.9: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of LPG carriers with the updated implementation schedule.

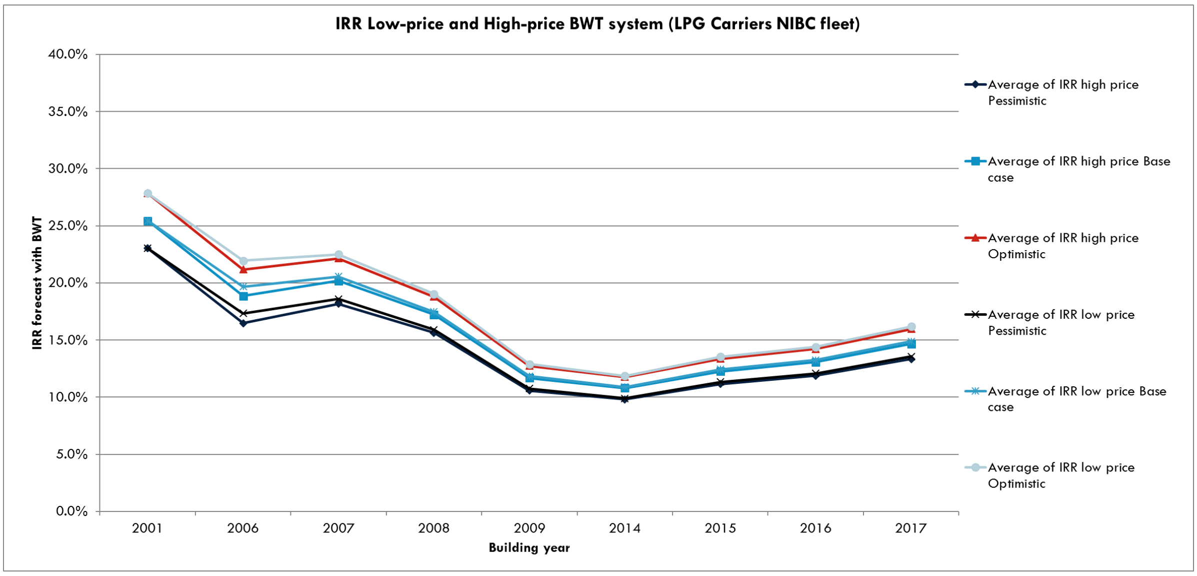

Figure F.10: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of LPG carriers with the updated implementation schedule.

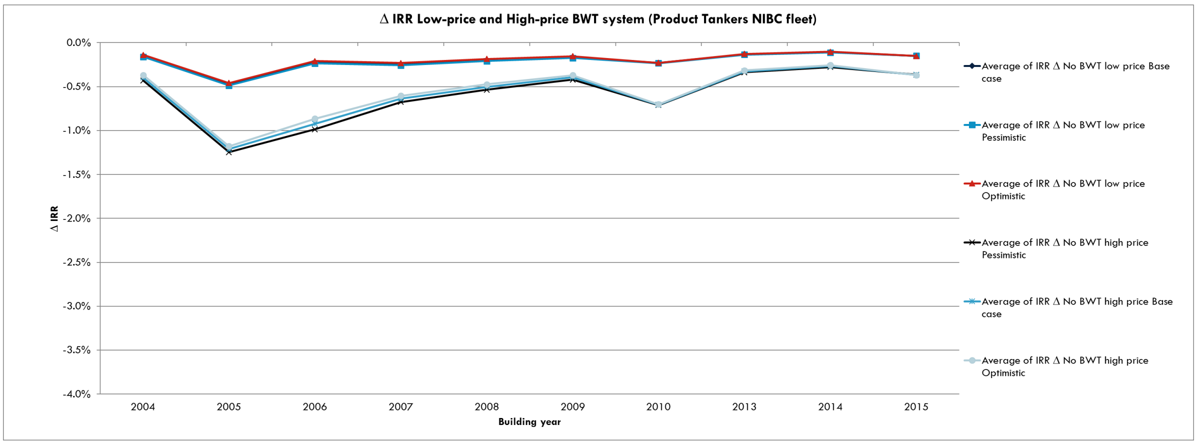

Figure F.11: Overview of the impact of the ballast water treatment system, high-price and low-price, on the IRR of the NIBC portfolio of product tankers with the updated implementation schedule.

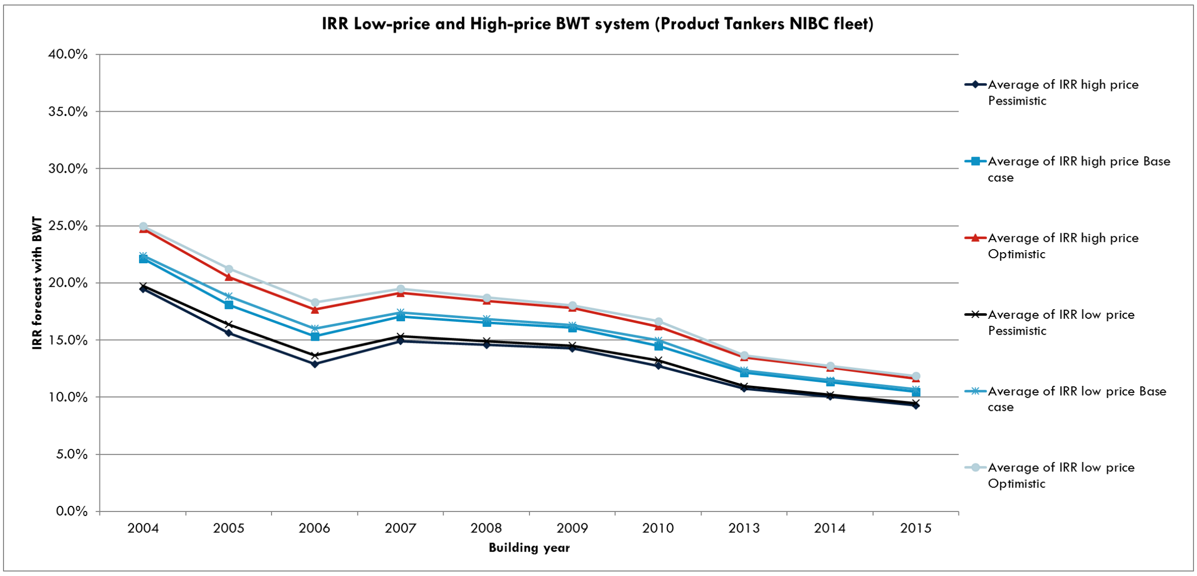

Figure F.12: Overview of the forecasted IRR with the installation of a ballast water treatment system, high-price and low-price, of the NIBC portfolio of product tankers with the updated implementation schedule.