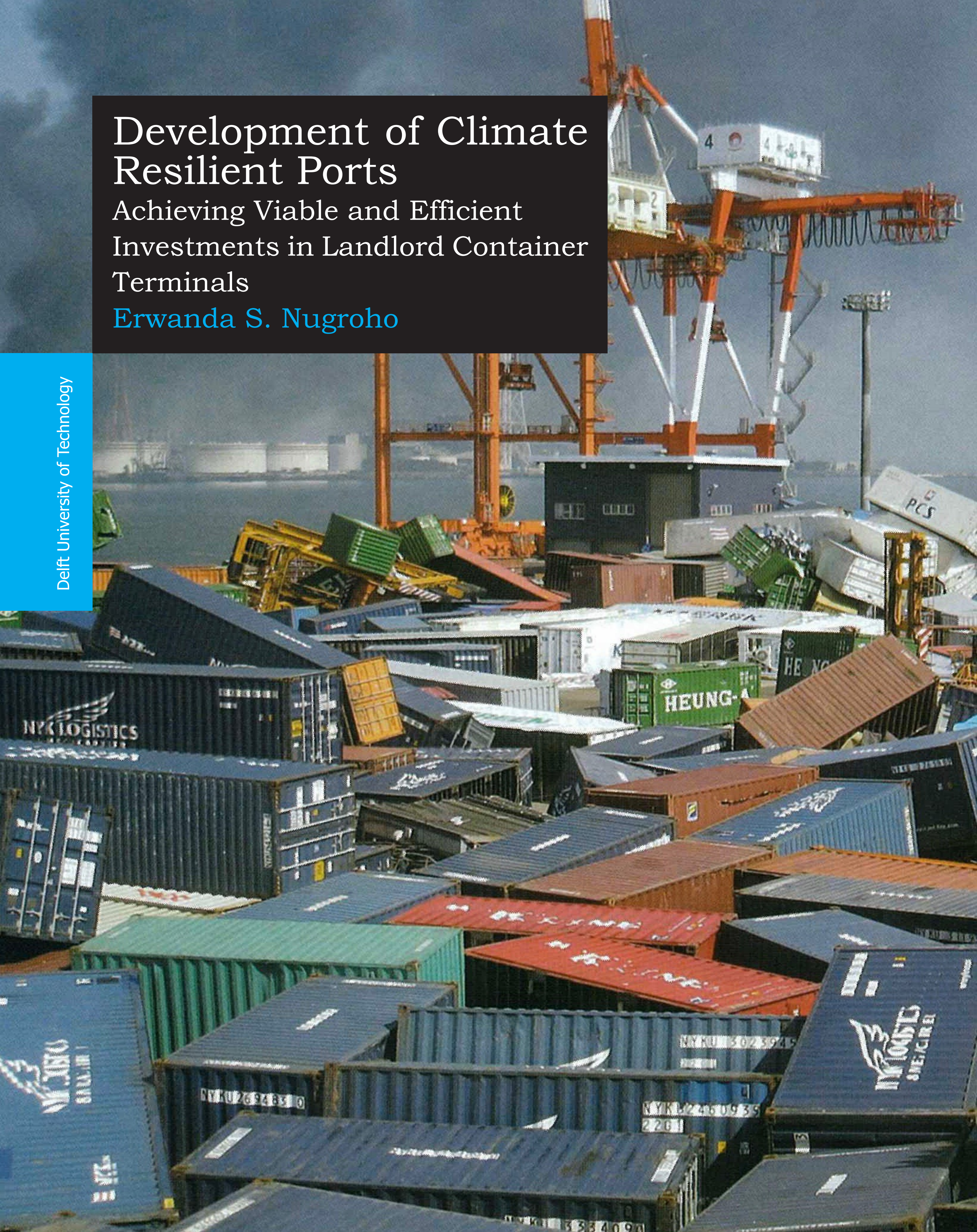

Development of Climate Resilient Ports

Achieving Viable and Efficient Investments in Landlord Container Terminals

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Development of Climate Resilient Ports

Achieving Viable and Efficient Investments in Landlord Container Terminals

By

Erwanda S. Nugroho

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Preface

This thesis is the end product of a five-month Master's thesis project conducted at Delft University of Technology and Deltares, which was initiated to contribute towards development of climate resilient ports. A series of problem explorations at the start of the study showed that a lack of investment in climate adaptation in ports is currently the main barrier to transform ports into climate-proof ones. Therefore, the research aimed to deliver a mechanism for achieving viable and efficient investments in building climate resilient ports. Subsequently, this document is mainly intended for port practitioners who, at some point in the future, will need to adapt their ports to climate change to maintain their ports operational and sustainable.

Nevertheless, in terms of writing style and content, this document aims to be conversational, simple and understandable to general public, thus sometimes elaborates more details. In this way, non-port practitioners who are interested in climate finance can also benefit from the outcomes of this research, although they might feel less connected as compared to port practitioners. Using the port sector as a unit of analysis, they could be encouraged to deliberate, debate and resolve the challenge of building climate resilient infrastructures faced by all climate-sensitive sectors worldwide.

This document consists of five different but interrelated parts. Part I primarily describes the background, objective, questions and methods of the research. In Part II, climate risks, opportunities and adaptation in ports are elaborated. An assessment matrix to support system-based and integrated evaluation of climate risks and opportunities for container terminals is presented in Chapter 3. A reader with interest in conducting such assessment is highly recommended to visit the chapter. In Part III, a methodological framework for approximating the viable and efficient investment option for adapting a port to climate change is presented. This part is certainly not to be missed, especially by readers who are willing and/or required to invest in climate resilient ports. In Part IV, a discussion of which port stakeholders are responsible for financing the viable and efficient adaptation option in a port is provided. A reader who would like to know how climate risks and responsibilities in a landlord container terminal could be effectively allocated among port stakeholders is encouraged to read this part. Lastly, in Part V, recommendations for achieving viable and efficient investments in climate resilient ports are delivered based on the outcomes of the research. In addition, an executive summary was prepared for those interested in the research but, alas, in hurry.

Erwanda S. Nugroho
Delft, August 2016

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The last five months have been one of the most intellectually fruitful periods in my life. As a student who had no mastery of financial analysis and no knowledge of port operations beforehand, completing this rather ambitious Master's thesis project was a kind of Mount Everest for me to climb. Clearly, I would not have made it without the support of many individuals around me. Therefore, I would like to thank them here. But, first and foremost, I would thank my God, Jesus Christ, for His blessings throughout my research, such that I am able to complete my thesis successfully.

Next, I would like to express my deep and sincere gratitude to all of my graduation committee members. I would thank my graduation chairman, Dr. ir. Bert Enserink, for convincing me to take up this Master's thesis project and his constructive comments. To my first supervisor, Dr. Jill Slinger, for her continuous support and supervision, especially in the beginning of my project, during which I had some difficulties to scope my research and my official start date had to be delayed by a month. Dr. Servaas Storm, my second supervisor, for being present and helpful whenever I needed his assistance with executing the required financial analysis. More importantly, I would like to thank him for his inspiring lectures on Economics, which also motivated me to choose this thesis project. To Dr. ir. Cornelis van Dorsser, for his critical feedback that have enhanced the quality of my Master's thesis. Dr. ir. Mónica Altamirano, my daily supervisor at Deltares, for her guidance, feedback and suggestions throughout the project. To Dr. ir. Martijn de Jong, for his constructive feedback and support throughout my internship at Deltares. Finally, I would like to thank six of them for allowing me to take time out of their hectic schedules. I hope that this thesis reflects their valuable input well.

Afterwards, I would like to thank Mr. Vladimir Stenek, Mr. Alan Duque Perez and Prof. Tiedo Vellinga for their willingness to be interviewed for this project. Their fields of expertise and knowledge were of great importance for the success of the two case studies presented in this thesis. I would also like to thank my colleagues and fellow interns at Deltares for making me feel so welcome in the office. In particular, I thank Ruben van Dijk, Judith Mol and Margarita Tsavdaroglou for all discussions about our Master's thesis projects, which are clearly interconnected. I hope that all of them can gain benefits from this thesis. I also want to thank Arvid de Rijck, Clotilde Peyroche d'Arnaud, Hugo de Rijke and other fellow interns for our coffee breaks and cake sessions.

I am also grateful to all of my friends at the university, with whom I share my doubts, sadness, happiness, jokes and future plans. I thank all of my Engineering and Policy Analysis classmates, who I met and collaborated to gain knowledge of the world of policy analysis. In particular, I would like to thank Buse Tali, María José Galeano Galván and Andita Rahmi Faradina for sharing their experiences about their Master's thesis projects, which have somehow strengthened me through all tough phases of my thesis. Finally, I want to give thanks to all of my family members who have supported me during my two years of study in the Netherlands. I would specially express my gratitude to my parents, who successfully persuaded me to pursue a post-graduate degree.

Erwanda S. Nugroho
Delft, August 2016

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Executive Summary

The impacts of climate change on ports are gaining importance as they could reduce the functionality of ports and therefore negatively affect the effectiveness of global supply chain network. However, the need for adapting ports to climate change may not have been adequately acknowledged by port stakeholders. Based on a series of problem explorations, three barriers that have hindered them to sufficiently adapt their ports to climate change were recognized. Firstly, different ports require distinct climate adaptation measures as they have dissimilar climate conditions, engineering structures and operations. In this regard, an effective general best practice of climate adaptation for ports does not exist, such that each port is required to identify its effective and feasible adaptation measures by itself. Secondly, the inability to predict future climate with considerable accuracy induces uncertainty regarding the viability and efficiency of investments in the measures. As a consequence, port stakeholders could be hesitant to finance the measures. Last but not least, the multi-stakeholder partnerships in port development and operations have led to unclarity about which port stakeholder is responsible for financing each measure.

This research aimed to address the three aforementioned knowledge gaps within climate risk management in ports by delivering a mechanism for achieving viable and efficient investments in climate resilient ports. Subsequently, using the landlord container terminal as a unit of analysis, the following research question was constructed and explored: *"Under what conditions and how can viable and efficient investments in climate resilient ports be achieved?"*

Climate Risks, Opportunities and Adaptation in Ports

The first step to ensure the viability and efficiency of investments in climate resilient ports is to acknowledge the significant climate risks and opportunities, as well as the effective and feasible climate adaptation measures for ports. By carrying out an extensive literature review, various climate risks and opportunities for container terminals were identified. They were tabulated and then transformed into a climate risks and opportunities assessment matrix for the terminals. The matrix was developed in a way such that it indicates which terminal sub-operations and assets are potentially affected by each of the climate change impacts and adverse weather events. Therefore, the effective adaptation measures for the terminals could be determined in an enhanced manner. The measures can be recognized by (1) exploring relevant literature of climate adaptation in ports, (2) learning from climate adaptation plans and/or practices in terminals that share similar climate risks and (3) conducting an in-depth engineering study to explore for additional potential measures and evaluate the feasibility of each identified measure.

Evaluating the Viability and Efficiency of Climate Adaptation Investments in Ports

Secondly, after the effective and feasible measures are identified, it was found beneficial to evaluate the viabilities and efficiencies of different investment options in the measures. This research suggests that all significant climate risks in a port should be valued in monetary terms and incorporated into the port business model. Otherwise, it is hardly possible to effectively assess the financial viabilities of the measures and the financially efficient investment option in executing them. An exploration of financial methods suitable for performing the evaluation indicates that an integration of Weather Value at Risk (Weather-VaR) and Real Options Analysis (ROA) has potential to approximate the viable and efficient investment option for adapting a port to climate change.

Firstly, Weather-VaR allows significant risks to be valued in monetary terms and hence incorporable into the port business model. Secondly, after the benefits of climate adaptation in terms of reduction or elimination of the risks are directly comparable to its costs using the Weather-VaR method, ROA could be utilized to assess the viability of each possible adaptation investment option. This research proposes the Value at Risk of return on each investment option to be assessed for analyzing its financial viability. In this way, the chance of having loss on the adaptation investment can be reduced to the risk tolerance of the investor. Lastly, ROA is also capable of estimating the efficient investment option out of the viable ones by evaluating the expected net present values of all viable options. The option with the highest expected net present value could be considered as the efficient one as it is most likely to deliver the highest investment return taking into account the uncertain future climate. The potential of the proposed integration of Weather-VaR and ROA has been partially confirmed by a fictitious case study on Terminal Maritimo Muelles el Bosque. However, its generalizability could not be entirely concluded by the research as the terminal was only subjected to a single climate risk (i.e. sea level rise).

Financing Climate Adaptation in Ports

After the viable and efficient option for investing in climate adaptation in a port is known, it is also important to recognize the appropriate financer for each adaptation measure. By reviewing (1) the existing contractual protections against climate risks in landlord container terminal partnerships and (2) the barriers to incorporate effective allocation of climate risks into the partnerships, the research infers that the responsible financer could be effectively determined if the stakeholder in charge of dealing with each climate risk is explicitly specified in the partnership agreements.

The assignment could be done in two complementary ways. Firstly, all unmitigable and unmitigated climate risks can be classified into relief, compensation, force majeure, insured and uninsurable events. To ensure the effectiveness of the contractual protections during the partnerships, the appropriate thresholds of likelihood and/or consequences for each of the climate risks could also be specified. In this way, once any threshold is reached, the contractual protection applicable to the relevant risk can be altered to a more appropriate one through either variation or renegotiation clause. Secondly, for all climate risks that would be mitigated during the partnerships, the required climate resilience levels for each port infrastructure and operation against them could also be stated. Moreover, the parties in charge of delivering such performances and any penalty imposed on them for failing to meet their obligations can be clearly stipulated.

By implementing the proposed actions, the stakeholder responsible for financing each effective and feasible climate adaptation measure in a port could be acknowledged. However, although the potential of the recommended actions has been confirmed by the recent success of climate risks allocation in Maasvlakte II and a published scientific article on the need for adaptive standards in infrastructure contracting by Altamirano et al. (2015), future research is still needed to enhance their applicability. This is because their implementations are dependent on an accurate and effective monitoring system for the relevant threshold variables and the achieved resilience levels, which has not been addressed in the research.

Answers to the Research Question

From the research findings, the following climate risk management practices in ports are found beneficial for achieving viable and efficient investments in climate resilient ports:

I. The significant climate risks and opportunities in ports, as well as the port sub-operations and assets susceptible to the risks should be recognized.

II. From the knowledge of the potentially affected sub-operations and assets, effective and feasible adaptation measures for the ports have to be determined.

III. The significant climate risks, as well as the effective and feasible adaptation measures should be valued in monetary terms and incorporated into the port business models.

IV. Based on the outcomes of the assessments, all identified climate risks should be classified into (1) climate risks that are unmitigable or are left unmitigated and (2) those would be mitigated during port partnerships.

V. For all unmitigable and unmitigated climate risks, they shall be classified into relief, compensation, force majeure, insured and uninsurable events.

VI. To ensure the effectiveness of the contractual protections during the partnerships, the protection applicable to each of the unmitigable and unmitigated climate risks should be altered once it is no longer appropriate.

VII. For climate risks that would be mitigated during the partnerships, the required climate resilience levels and the port stakeholders in charge of delivering such performances have to be clearly stipulated.

Policy Implications and Recommendations

From the research outcomes, in particular the answers to the research question, the following six recommendations were derived to achieve viable and efficient investments in climate resilient ports (actors indicated in bold):

I. **All port stakeholders** are suggested to join hands for conducting system-based and integrated assessments of climate risks and opportunities for their ports to identify port sub-operations and assets vulnerable to the risks.

II. **Port authorities** and **all other port stakeholders whose operations and assets are potentially affected by the identified climate risks** are encouraged to explore the effective and feasible climate adaptation measures for their vulnerable operations and assets.

III. **Port authorities** and **the other potentially affected port stakeholders** are advised to value the risks in monetary terms such that they are incorporable into their business models. In this way, the viable and efficient climate adaptation investment options for their ports can be approximated.

IV. **Port authorities** and **the other potentially affected port stakeholders** are recommended to categorize climate risks in their ports into two classifications of (1) climate risks that are unmitigable or are left unmitigated and (2) those would be mitigated during their partnerships. The following set of decision rules could be employed for classifying the risks:
   - Climate risks without any effective and feasible adaptation measure can be classified as unmitigable risks.
   - Climate risks with no viable investment option to execute their corresponding effective and feasible adaptation measures can be considered as the risks that are left unmitigated.
   - Climate risks with viable investment options to execute their corresponding effective and feasible adaptation measures can be categorized as those would be mitigated.

V. **Port authorities** and **all other port stakeholders potentially affected by the unmitigable and unmitigated risks** are suggested to assign each of the risks into the currently suitable contractual protection type. Moreover, to address the issue of rising unmitigable and unmitigated risks, the appropriate thresholds of likelihood and/or consequences for each of them could be incorporated into the partnerships. Further, they are encouraged to make pre-agreements on how the transition of contractual protection applicable to each risk should be performed once any of the relevant thresholds is reached.

VI. As governors of operations in landlord ports, **port authorities** are advocated to take the lead role in discussing the responsibilities for mitigating climate risks that would be reduced and/or eliminated during port partnerships with **other port stakeholders**, and explicitly allocate the responsibilities afterwards.

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Part I

Introduction

Chapter 1 - Thesis Definition

1.1 Research Background

The issue of climate change impacts on ports is becoming more important. A number of experts participated in the *Ad Hoc Expert Meeting on Climate Change Impacts and Adaptation: A Challenge for Global Ports* held by the United Nations Conference on Trade and Development in September 2011 has stated their concern on the matter explicitly:

"Given the strategic role of ports as part of the globalized trading system, adapting ports in different parts of the world to the impacts of climate change and building their resilience is an urgent imperative." (UNCTAD, 2011, p. 2)

Text Box 1.1: Relevant Concepts

- **Climate change** refers to a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties for an extended time period (IPCC, 2007, p. 30).
- **Climate adaptation in port** describes any adjustment in port assets, operations and organizations in response to climate change, which moderates the harms and exploits the opportunities. The definition is adapted from IPCC (2011) as cited by Nursey-Bray et al. (2013, p. 1022).
- In this thesis, **climate resilient port** characterizes a port that is capable of (1) maintaining its most important functions when subjected to disturbances induced by climate change and (2) returning to its fully desired functionality following the disruptions. The definition is adapted from de Bruijn (2005, p. 22).

What are the contributions of ports to today's economy? How does climate change affect them? Are ports currently building their resilience to climate change? This section addresses these questions briefly but to the point; the answers also serve as the background information for the research problems discussed in Chapter 1.2.

1.1.1 The Importance of Ports for Economy

The world economy has been characterized by trade specialization, which is induced by the ability of different nations to offer particular products and services at lower prices and/or higher qualities (Porter, 1990; Roa et al., 2013). The specialization is beneficial for both importers and exporters. On one hand, it allows industries and consumers to have access to high quality but low-price commodities. In this case, industries can enjoy higher profit margins, while consumers are able to enhance their well-being. On the other hand, it has led to the development of countries with export-led economic growth, including China, India, Taiwan and South Korea (Tang et al., 2015). These benefits have increased the global trading volume and raised the dependency of world economy on the trading. Therefore, sustaining global trading is of great importance.

Nowadays, ports play a key role in the global economy. The fact that about 90% of world trade is carried by maritime transportation suggests that the economy is reliant on sustainable and effective port operations (IMO, 2013). Moreover, as points of convergence in the global supply chain network, ports act as the gateway to trade and provide different regions with access to global market (Ng et al., 2013). Apart from its role in facilitating global trade, ports have a significant contribution to national gross domestic products by enabling nations to export their commodities (Dwarakish & Muhammad, 2015). Further, ports serve as catalysts to the related and nearby industries, such as shipping, industrial and manufacturing companies (Coppens et al., 2007). All in all, ports are crucial components of national infrastructure portfolios and are considered vital to economic development.

1.1.2 Climate Change Impacts on Ports

However, the growing intensity of climate change is becoming a threat to the world economy as ports and their hinterland connections are very vulnerable to the impacts of climate change (Becker et al., 2012). The vulnerability is mainly explained by their locations in sensitive estuarine environments, such as in coastal areas susceptible to sea level rise and storms, as well as at mouth of rivers with high risk of flooding (Emanuel, 2013; Hallegatte, 2008; Ng et al., 2013). Being the nodal points in global supply chain network, port operations disrupted by negative climate change effects would bear significant costs (Ng et al., 2013), as shown in Table 1-1. Such incidents have led to chain reactions that adversely affected the global supply chain network and hence slowed down the global economy. For instance, the closure of the Port of Newcastle induced large financial losses to Australian coal exporters, while at the same time forced Asian coal importers to seek alternative supplies from Indonesia and South Africa for sustaining their businesses (Stenek et al., 2011). The high dependency of the global economy on sustainable port operations implies that the consequences of climate change on ports are significant.

Table 1-1: Examples of financial consequences of adverse weather events in ports

Port	Main cause of disruption	Estimated financial loss[1]	Source
A port in Western Australia	Extreme cyclones	3.0 billion AUD	Ng et al. (2013)
Texas ports, USA	Hurricane Ike	2.4 billion USD	FEMA (2008)
Southern Louisiana ports, USA	Hurricane Katrina	1.7 billion USD	Santella et al. (2010)
The Port of Newcastle, Australia	Extreme storms	1.0 billion USD	Port World (2007)

1.1.3 The Current State of Ports in Adapting to Climate Change

Nevertheless, the need for adapting ports to climate change may not have been adequately acknowledged by port stakeholders. Although a majority of port stakeholders have discussed and developed climate adaptation plans for their ports (Becker et al., 2012), more than two-third of port stakeholders participated in a survey study of Nursey-Bray et al. (2013) state that it is too early to act as substantial uncertainties about future climate still remain. In this case, a majority of the developed adaptation plans would not be converted into actions. Therefore, the functionality of ports and the effectiveness of global supply chain network continue to be at risk of climate change.

1.2 Research Problems

Based on a series of problem explorations at the start of the research, three barriers that have hindered port stakeholders to adapt their ports to climate change sufficiently were found and they were subsequently addressed in this thesis. This section elaborates the gaps and motivates why they have to be tackled to successfully achieve the development of climate resilient ports.

1.2.1 Diverse Climate Profiles of Ports

Ports across the globe face different climate risks and opportunities as they have dissimilar climate conditions (Naruse, 2011). For instance, rising average annual air temperature may provide opportunities for ports situated in high-latitude as their uptimes are expected to rise and their expenditures for clearing ice shelf on waterways could decline (Stenek et al., 2011). In contrast, it may negatively affect ports located in mid-latitude and low-latitude as they would face more intense competition among ports due to the enhanced functionality of high-latitude ports. Moreover, the rising temperature may increase their energy demands for refrigeration and hence their energy bills (Stenek et al., 2011). Further, during extreme heat waves, port labors may have to be restrained from working by law, leading to disruption in port operations (Chhetri et al., 2016).

Therefore, developing a best climate adaptation practice for ports might not directly allow port stakeholders to recognize effective adaptation measures for their ports. As different ports are affected by climate change in distinct ways, some measures considered in such practice would be irrelevant for a particular port. Moreover, as they are constructed and operated in non-identical manners, some measures would be not implementable in several ports. Hence, what is more needed is the development of a general assessment tool for identifying climate risks and

[1] AUD: Australian Dollar, USD: United States Dollar

opportunities that are influential to the operations of different ports. Based on the assessment outcomes, effective and feasible climate adaptation measures for them could be acknowledged in an enhanced manner.

1.2.2 Uncertainty Regarding the Viability of Climate Adaptation Investments in Ports

Based on the findings of Nursey-Bray et al. (2013), it can be deduced that the inability to predict future climate with desirable accuracy leads to uncertainty about the financial viabilities of climate adaptation measures for ports. To the best knowledge of the author, most of the developed adaptation plans have not indicated the exposure of port business models to climate risks and opportunities explicitly (City of Port of Phillip, 2010; Port of San Diego, 2013; Rotterdam Climate Initiative, 2014), except for the analyses conducted by Stenek et al. (2011) and Connell et al. (2015) for Terminal Maritimo Muelles el Bosque and Port of Manzanillo, respectively. Nevertheless, both analyses simply assume that the climate evolution will follow one of the considered projections[2]. Hence, if the future climate does not follow the projections accordingly, the adaptation plans may lead to misleading outcomes as the recommended adaptation measures would be either insufficient or redundant.

Because of the absence of quantification of climate risks into port business models, port stakeholders would fail to (1) realize the negative impacts of climate change and (2) appreciate the positive contributions of the effective and feasible adaptation measures. To support ports in decision making about the viable options for financing the measures, incorporating the measures and their associated climate risks into port business models is required. The incorporation will allow the risks to be monetarily valued into the business models, such that the benefits and costs of the measures are monetarily comparable. In this way, not only their financial viabilities, but also the financially efficient climate adaptation investment option[3] for a port can be estimated.

Although it is very tempting to maximize the outcomes of climate adaptation investments in ports, the author admits that optimization might not be the best approach in the context of climate adaptation. This is because climate change can be classified as a deeply uncertain issue, in which one is capable of generating multiple future climate projections without being able to rank the chance of each scenario to occur. In this case, according to Agusdinata (2008, p. 45), regret-minimization approach is more appropriate than optimization. Therefore, whenever suitable and possible, the approach is incorporated for recommending investment options in climate resilient ports. In this way, the outcomes of this research could still be beneficial for decision makers or financers who prefer to minimize the possibility of loss on their climate adaptation investments.

1.2.3 Unclarity of Responsible Financers of Climate Adaptation in Ports

In the current trend of port partnerships, the port stakeholder responsible for financing each climate adaptation measure is rather not so easily determined. At present, landlord port is the dominant port governance model adopted in large and medium-sized ports (The World Bank, 2007). In a landlord port, the port authority is the owner of land and large-scale port infrastructures and grants concessions to private port operators, which are required to provide goods handling, transportation and storing services with their own superstructures and vehicles for a certain time period (Ligteringen & Velsink, 2012; Sorgenfrei, 2013; The World Bank, 2007). As the duration of the concession is generally shorter than the time-span required for experiencing significant climate change impacts, port operators may have a tendency to neglect the need for climate adaptation. This is because a high portion of benefits offered by the adaptation could accrue after the concession, such that the operators might perceive climate adaptation in ports as an unattractive investment. Therefore, it is important to explicitly state which stakeholder is responsible for financing each of the essential climate adaptation measures as one of the steps to transform them into actions.

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[2] Stenek et al. (2011) base their analysis on two future sea level projections, which are linearly and exponentially rising sea level scenarios, while Connell et al. (2015) ground their financial study on five different future precipitation and storm scenarios, which are: (1) current historical averages, (2) 25% reductions in the frequencies, (3) 50% reductions in the frequencies, (4) 25% increases in the maximum intensities and (5) 50% increases in the maximum intensities.

[3] An example of different adaptation options in ports against sea level rise: Raise the port infrastructures by (1) 100mm, (2) 200mm, (3) 300mm, (4) 400mm, etc.

1.3 Research Objectives and Questions

All in all, the research aimed to address the principal knowledge gaps within climate risk management in ports resulting from the research problems described in Chapter 1.2. The gaps are about (1) what climate risks and opportunities are significant to the operations of a port, as well as what are the effective adaptation measures for the port, (2) how to finance the measures viably and efficiently and (3) which port stakeholders are in charge of financing them. To date, these gaps have been translated into limited discussion about climate risk management in port planning (Becker et al., 2013). Therefore, a raise in viable and efficient investments in climate resilient ports could be expected from the outcomes of this research.

To operationalize the objective, the main research question answered in this thesis was delineated as:

Under what conditions and how can viable and efficient investments in climate resilient ports be achieved?

In this thesis, a viable investment is defined as an investment that allows the financer to gain benefit from the invested capital. Moreover, an efficient investment refers to the one that achieves the maximum return with the minimum expenses. Furthermore, to address the main question effectively, the research entailed answering the following sub-questions:

1) What are the significant risks and opportunities from climate change for ports, and what are the effective climate adaptation measures for them?
2) What is the viable and efficient investment option for adapting a port to climate change?
3) Which port stakeholders are responsible for financing the adaptation?

The sub-questions were derived from the gaps presented in Chapter 1.2. In this way, climate risks and opportunities, as well as the potentially effective adaptation measures for ports are recognized in the first place. Then, the viable and efficient option to invest in adapting a port to climate change can be approximated. Afterwards, once the financially efficient adaptation option for the port is acknowledged, the stakeholders in charge of financing the measures could be assigned.

1.4 Research Scope

In this research, due to time limitation, only one port business unit and a specific port governance model were considered. Quick scans of various port business units and port governance models were performed to select the most appropriate ones for this research[4]. In the first place, port business units of general cargo terminal, container terminal, bulk terminal, Roll-on/roll-off and ferry terminal, cruise terminal, fishery port and marina were explored. The exploration suggests that container terminal is the most suitable business unit for this research because of two main reasons. Firstly, as operations of container terminals are more or less uniform across the globe, the outcomes of this research could be applicable to a majority of container terminals. Secondly, containerization has been rising significantly and it is expected to carry about 60% of value of goods shipped by maritime transportation in just five decades (World Shipping Council, 2016).

In the second place, landlord port governance model has been selected for addressing the third research sub-question as both the port authority and private port operators play roles in the ownership and operation of port assets in a landlord port, as shown in Table A-1 (in Appendix A). In contrast, in service and private ports, all port assets are owned and operated by the public port authority and a private entity, respectively. Moreover, in a tool port, the private sector only provides port labors for operating port assets owned by the public authority. Therefore, port stakeholders responsible for financing climate adaptation measures in port models other than the landlord one are relatively more apparent. All in all, in this thesis, port operations are demarcated as operations of landlord container terminals.

[4] Readers interested in the elaborations of various port business units and port governance models are suggested to consult Chapters 7 – 13 of Ligteringen and Velsink (2011) and Appendix A, respectively.

1.5 Research Methods

Specific research methods employed to answer the research sub-questions are presented in Table 1-2. As shown from the table, the research was based on a mixture of case study, qualitative and quantitative methods. Each of the methods is elaborated in this section.

Table 1-2: Methods employed in the research

Sub-question	Research methods
1	Literature review
2	Weather Value at Risk, Real Options Analysis, quantitative case study, literature review and interviews
3	Qualitative case study, literature review and interviews

1.5.1 Case Studies

In this research, two different case studies were carried out for dissimilar motives. The first case study, which is a quantitative one, was aimed to (1) illustrate the application of an assessment framework developed for evaluating the viability and efficiency of climate adaptation investments in ports and (2) enhance the framework based on the limitations encountered from the application. A quick scan of climate risk assessments conducted for various ports was performed to select the most appropriate port. The scan reveals that the assessment for Terminal Maritimo Muelles el Bosque (TMMeB) by Stenek et al. (2011) was the only one that has considered the financial impacts of climate risks and the costs of the effective adaptation measures, despite the limitations previously discussed in Chapter 1.2. Hence, TMMeB was selected for the study.

The second case study was performed to examine the current success factors for allocating climate risks and responsibilities in ports among port stakeholders. The study was expected to assist in answering the third research sub-question. After a brief screening of climate adaptive capacities of different ports, the Port of Rotterdam was selected for the study as its city has been hailed as the best city in terms of its climate adaptation strategies and subsequently the perfect showcase for climate adaptation (C40 Cities Climate Leadership Group, n.d.). Following the selection, it was found that the Port of Rotterdam Authority has included sustainability criterion in the tendering of one of its container terminals in Maasvlakte II (The Port of Rotterdam Authority, n.d.a). Therefore, the study was further specified into the climate risk management in Maasvlakte II.

1.5.2 Qualitative Research Methods

Qualitative research methods are of great importance for the research as literature review and interviews contribute in answering the research sub-questions. First of all, literature review was found very suitable as the starting point of each research sub-question. This is mainly because such review helps avoiding any research duplication (Aitchison, 1998 as cited by Khan & Law, 2015) and could allow the author to extract the required information in the least time possible.

Secondly, several interviews with different purposes were also conducted to aid in answering the second and third sub-questions. All of the interviews can be classified into three distinct interview sets. The purpose, method and communication medium of each interview set are summarized in Table 1-3. As shown in the table, the adopted interview method varies with the motive. On one hand, for the reason of obtaining additional information required for executing a case study on TMMeB, structured interview method was selected. This is because most of the required data have been reported in Stenek et al. (2011). Therefore, only several specific additional details were required from the respondents. Moreover, due to the absence of field trip to TMMeB and the preference of the respondents, the interviews had to be conducted through e-mails, such that the author could not adapt his questions based on their responses. On the other hand, semi-structured interview was chosen for extracting information from a respondent when verbal communication was possible. In this case, the author could match the questions based on the expertise of the respondent and the flow of discussion (Bryman, 2008), while still in control of the interview direction at the same time. In contrast, unstructured interview, in which no question is arranged beforehand, was conducted for validation purpose. This is because it allows the author to present his research findings and let the respondent to construct and share his views on the findings freely (McLaughlin, 2003).

Table 1-3: Overview of interviews conducted in the research

Interview set	Interview purpose	Interview method	Medium of communication
1	Obtaining additional details required for the TMMeB case study	Structured	E-mail
2	Extracting information about climate risks and responsibilities allocation agreement in Maasvlakte II	Semi-structured	Face-to-face interaction
3	Validating the analysis of success factors of the Port of Rotterdam Authority for allocating climate risks and responsibilities in Maasvlakte II	Unstructured	Telephone communication

In each interview set, a selection of potential respondents was initially performed, such that the most relevant and potentially most knowledgeable informant could be identified and firstly interviewed. For instance, Mr. Vladimir Stenek, the first author of climate risks assessment report for TMMeB was approached and interviewed at first in interview set 1. In this way, the number of performed interviews could be minimized, such that the research was conducted in a timely and efficient manner.

1.5.3 Quantitative Analysis Methods

Two different quantitative methods were employed for developing a framework for assessment of the viabilities and efficiencies of different climate adaptation investment options in a port. Firstly, Weather Value at Risk (Weather-VaR) was chosen for valuing financial benefits of climate adaptation measures in ports, which are generally less determinable as compared to their costs because of uncertainty in future climate. The method integrates (1) the probability of occurrence of adverse weather events and (2) the sensitivity of a financial performance to the events (Prettenthaler et al., 2016; Toeglhofer et al., 2012). It has been successfully applied for (1) analyzing the impacts of weather variability and climate change on the financial performance of accommodation industry in Kitzbuehel (Toeglhofer et al., 2012) and (2) assessing the financial impacts of climate change on wheat cultivation and summer tourism in part of Sardinia (Prettenthaler et al., 2016). Therefore, it was intriguing to explore the feasibility of Weather-VaR to value climate risks into port business models and assess the viabilities of different investment options in the proposed climate adaptation measures.

Secondly, Real Options Analysis (ROA) was selected to determine the viable and efficient investment option for adapting a port to climate change. The analysis, which was originated from financial options, has been applied in almost every industry during the past decade (Wang & Halal, 2010). According to Herder et al. (2011), it recognizes projects as processes that take place over time and can be subdivided into smaller sub-projects for dealing with uncertain future developments. Moreover, as described in Taneja (2013, p. 101), the method is appropriate for appraising any project with deeply uncertain future, as long as likely scenarios can be sufficiently specified. As several attempts have been made to extrapolate future climate variables by taking into account the uncertain climate change, ROA was found suitable for approximating the efficient adaptation investment option.

While Weather-VaR is unique, various variants of ROA exist. Literature review of the application of ROA in engineering projects revealed that (1) decision tree analysis, (2) Binomial Option Pricing Method, (3) Black-Scholes Option Pricing Model and (4) spreadsheet analysis have been employed for valuing options in engineering projects (Cardin et al., 2015; de Neufville, 1990; de Neufville et al., 2006; Wang & de Neufville, 2005; Wang & Halal, 2010). Moreover, based on the review, spreadsheet analysis was found to be the most appropriate variant for constructing the assessment framework because of three main reasons. Firstly, the more the options and time layers incorporated into decision tree analysis, the more difficult it is to evaluate the value of each option as the tree framework will become more complicated (Wang & Halal, 2010). Secondly, despite offering ready-to-use equations for the valuation, both Binomial Option Pricing Method and Black-Scholes Option Pricing Model are based on assumptions that do not fit in engineering projects, in particular the existence of active trading of options in engineering projects (Eschenbach et al., 2007). On the contrary, spreadsheet analysis was developed by de Neufville et al. (2006) for avoiding complex mathematical computation and financial procedures that do not match the circumstances of engineering projects[5].

1.6 Research Framework and Thesis Outline

The outline of this thesis, which was developed such that it is in line with the research framework, is presented in Figure 1-1. As depicted in the figure, this document consists of five different yet interconnected parts. Part I primarily elucidates the background, objective, questions and methods of the research. In Part II, (1) operations of container terminals, (2) climate risks and opportunities for the terminals and (3) currently available climate adaptation measures for them are elaborated. The key outcome of this research part is a general matrix for assessing climate risks and opportunities in container terminals. Part III presents (1) a proposed framework for evaluating the viabilities and efficiencies of climate adaptation options in ports and (2) its application on TMMeB, which enhanced the originally developed framework. In Part IV, the barriers encountered to explicitly incorporate climate risks and adaptation responsibilities among port stakeholders are described. Based on the identified barriers, guidelines for allocating climate risks and responsibilities in landlord container terminals were constructed. The applicability of the guidelines was then evaluated by exploring the recent success of climate risks allocation in Maasvlakte II. Lastly, Part V serves as the conclusion of this thesis, which delivers a set of potential action steps to achieve viable and efficient investments in climate resilient ports. Moreover, the limitations of the research are presented to pave the way for future research.

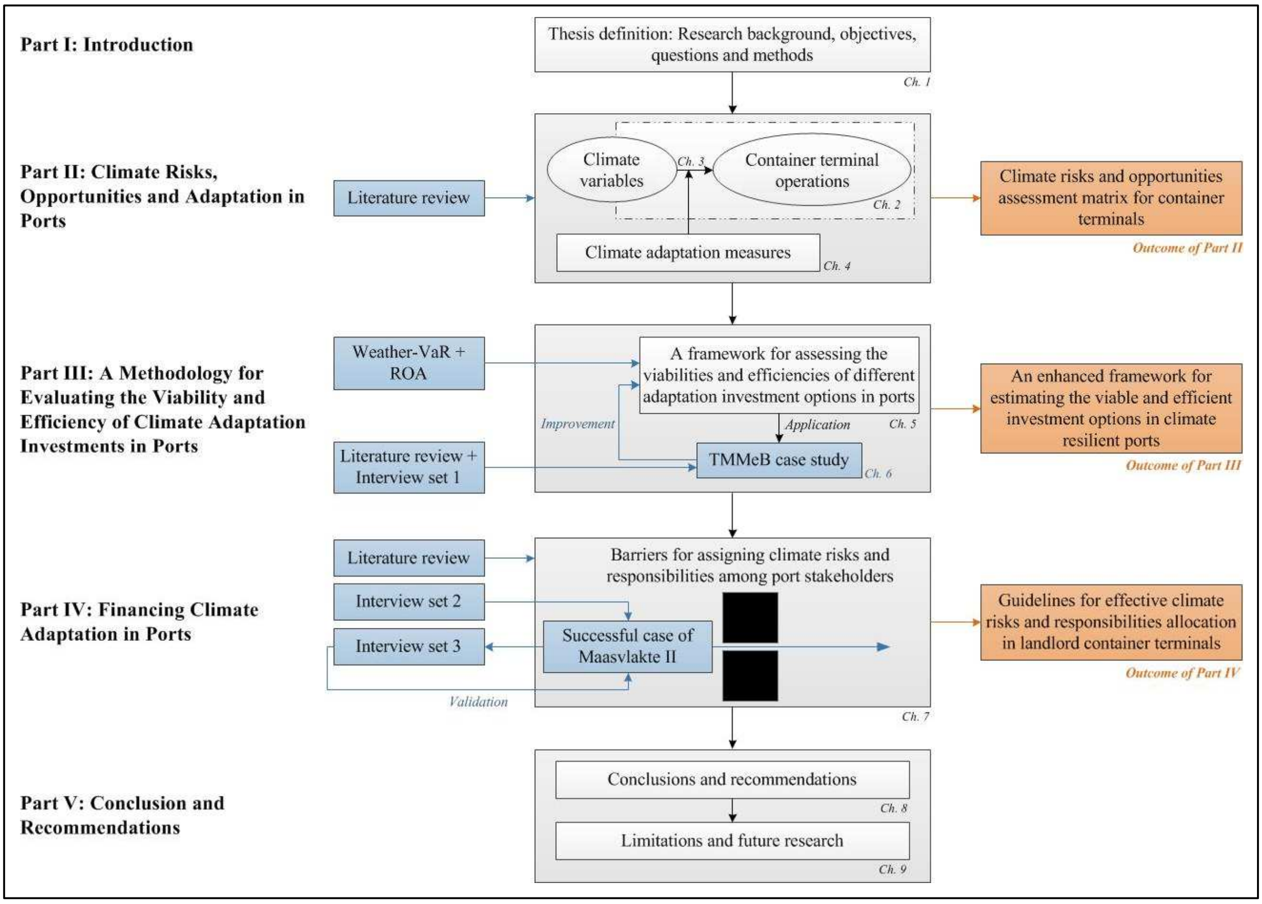

Figure 1-1: Research framework and thesis outline

[5] Brief descriptions of the unselected ROA variants are provided in Appendix B, while the spreadsheet analysis is elaborated in Chapter 5.2.

Part II

Climate Risks, Opportunities and Adaptation in Ports

Chapter 2 - Operations in Container Terminals

According to Steenken et al. (2004), container terminals can be generally thought of as open systems of goods flow between two interfaces of waterside and landside operations. Within the terminals, goods handling, ground transportation, goods storing and goods transfer to hinterland transporters are executed. The flow of containerized goods in a typical container terminal is illustrated in Figure 2-1.

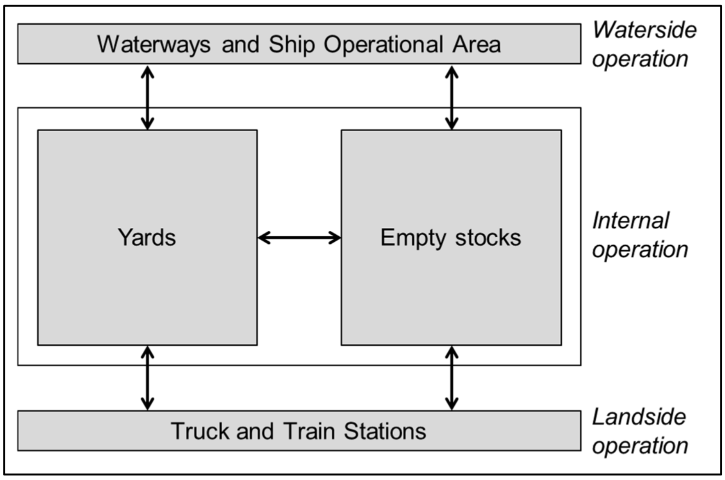

Figure 2-1: Operations in a typical container terminal, adapted from Steenken et al. (2004, p. 6)

First of all, waterside operation of (1) navigating the incoming container vessels in waterways and ship operational area and (2) mooring them at the quay using bollards connects the vessels to the terminal. Therefore, all import containers can be (1) extracted from the vessels, (2) transported to yards and empty stocks and (3) stored there. These three sub-operations fall into the internal operation of the terminal. Once the containers are ready to be picked up by hinterland transporters, they are delivered to truck and train stations situated in or nearby the terminal and subsequently transferred to the transporters. The delivery and transfer processes are regarded as the landside operation of the terminal. The reverse flow of goods applies for export containers, which are firstly transported to the truck and train stations by hinterland transporters and later conveyed to container vessels for maritime transportation by the internal operation. Each operation in a typical container terminal is elaborated in this chapter.

2.1 Waterside Operation

Various types of container vessels are served in the waterside operation. For a large international container terminal, deep-sea vessel is considered as the most important vessel type as it is generally employed for trans-ocean shipment. To date, MSC Oscar, MSC Oliver and MSC Zoe are the largest deep-sea container ships in the world. Three of them are identical ships built by MSC and have a capacity of 19,224 container units, with length, breadth and draught of about 395 meters, 59 meters and 16 meters, respectively (ship-technology.com, 2010). Other than deep-sea vessels, some container terminals also accommodate feeder vessels and inland barges. On one hand, feeder vessels are mainly utilized for shipping containerized goods between international terminals and smaller regional terminals (Ligteringen & Velsink, 2012). On the other hand, inland barges are commonly used for transporting the goods between terminals and hinterland stations through rivers and water channels (Steenken et al., 2004).

The waterside operation mainly consists of two sub-operations of navigation and berthing. With the aids of Global Positioning System, Electronic Data Interchange, navigation lights, navigation buoyage and tugboats, each incoming container ship is navigated by marine traffic controllers and marine pilots to the pre-assigned quay. Quay is a structure constructed on the ground and adjacent to waterways, serving as the place for incoming vessels to moor while goods are being loaded into and unloaded from them. Fenders are generally installed on the edge of each quay and function as bumpers for absorbing kinetic energy of the incoming vessels and therefore preventing damage to both the vessels and berthing structure (Chhetri et al., 2013).

The operation also involves the construction and maintenance of waterways, sea locks and breakwaters, which are essential to accommodate the incoming and outgoing sea vessels. The water depth of waterways should be continuously monitored and maintained by dredging to ensure that the vessels can travel safely in the waterways. In some terminals, sea locks are installed for raising and lowering water level in certain areas of waterways, such that the vessels can still enter the terminal and maintain their draughts at low water level. Moreover, sea locks aid in controlling the water level in the berthing area, which changes due to the variation in astronomical tide in absence of any lock. Further, a breakwater is a coastal structure installed at the port entrance to protect the manoeuvring and moored sea vessels from sea waves, which could cause excessive motions of ships at the quays and therefore negatively affect the goods loading and unloading processes (PIANC, 2012a).

2.2 Internal Operation

On container vessels, containers are systematically placed in stacks and therefore only specific equipment are capable of loading and unloading them into and from the vessels, respectively. Quay cranes are generally installed on quays for handling such operations. In general, each crane is operated by a human operator, who manages the movement of crane trolley from the cabin. The operator moves the trolley over a ship or a ground vehicle to extract a container. Once the container is hooked by a spreader situated underneath the trolley, it can be lifted safely and placed on either (1) a container vessel for transhipment or (2) a ground vehicle for transportation to goods storing area or a hinterland transporter.

Containerized goods and empty containers received from both waterside and landside operations are stored in yards and empty stocks, respectively. They are generally stacked for efficient use of storage space. Some containers (i.e. reefers) require refrigeration and they are connected to power supply through reefer plugs while being stored in yards. All containers are transported between quays, yards, empty stocks, and truck and train stations using ground vehicles. There are various types of ground vehicles employed by container terminals. The choice is dependent on many factors, such as labor costs, as well as social and environmental factors (Steenken et al., 2004). According to Steenken et al. (2004), vehicles for performing ground transportation can be classified into first and second class ground vehicles.

On one hand, first class ground vehicles are incapable of lifting containers by themselves. They include trucks with trailers and Automated Guided Vehicles (AGVs). Truck with trailers, or commonly referred to as an extended truck, is operated by a human driver. Its capacity is dependent on the number and size of trailer pups. In contrast, AGVs are robotics; they are operated on a road network, which consists of electric wires or transponders to control the position and movement of each vehicle. AGVs require large investment and therefore are operated only in terminals with high labor costs (Steenken et al., 2004).

On the other hand, second class ground vehicles are capable of not only transporting goods on the ground, but also lifting containers to certain heights. Examples of this type of vehicles include straddle carrier, forklift and reach stacker. Straddle carrier is the most commonly used out of them because of its high vertical reach and its ability to stack and extract containers in goods storing areas directly. Therefore, it can be thought of as a mobile crane with free access to containers independent of their elevation levels. Its capacity is dependent mainly on its size of structural support and so does its vertical reach. In general, if no second class ground vehicle is operated in a container terminal, gantry cranes are employed to store containers in stack formation in yards and empty stocks.

All in all, the internal operation of a typical container terminal consists of goods handling, ground transportation and goods storing sub-operations. They are very interrelated and supported by internal data communication, which informs drivers and operators about (1) loading and discharging lists that specify which containers to be loaded into and unloaded from a particular vessel, (2) bayplan, which specifies the position of each container within a ship and the supporting stowage instruction and (3) job data or sequences (Ligteringen & Velsink, 2012).

2.3 Landside Operation

The landside operation of a container terminal solely comprises of the management of connection to hinterland connections, in which goods transfer between the terminal and hinterland transporters is performed. In most cases, container terminals are equipped with truck and train stations for accommodating such transfer. Electronic Data Interchange is mainly used as a mean of communication between terminal operators and forwarders for agreement on goods pick-up and delivery schedules. Once a truck or train arrives at the station, ground vehicles are deployed to the truck or train for facilitating the goods transfer. Moreover, if the terminal is connected to hinterland terminals through water channels, inland barges can be utilized for hinterland transportation. In this case, the waterside operation for accommodating the incoming barges also serves as the landside operation.

2.4 Summary of Operations and Assets in Container Terminals

As elaborated in Chapter 2.1 – Chapter 2.3, operations in a typical container terminal can be classified into six different but very interrelated sub-operations, which are (1) navigation, (2) berthing, (3) goods handling, (4) ground transportation, (5) goods storing and (6) connection to hinterland connections. In this way, terminal assets can also be categorized systematically, as shown in Figure 2-2. The presented assets are generic as the classification attempts to consider essential assets in all container terminals. Therefore, it should be noted that several assets may not present at some terminals. For instance, to the knowledge of the author, AGVs are currently being operated in only the Port of Rotterdam and the Port of Hamburg. Moreover, not all container terminals own both train and truck stations for facilitating goods transfer between the terminals and hinterland transporters. As shown in Chapter 3 and Appendix A, the classification aids for understanding (1) how various climate change impacts and adverse weather events affect the operations of a terminal, (2) which port stakeholders function each sub-operation and (3) own the supporting assets.

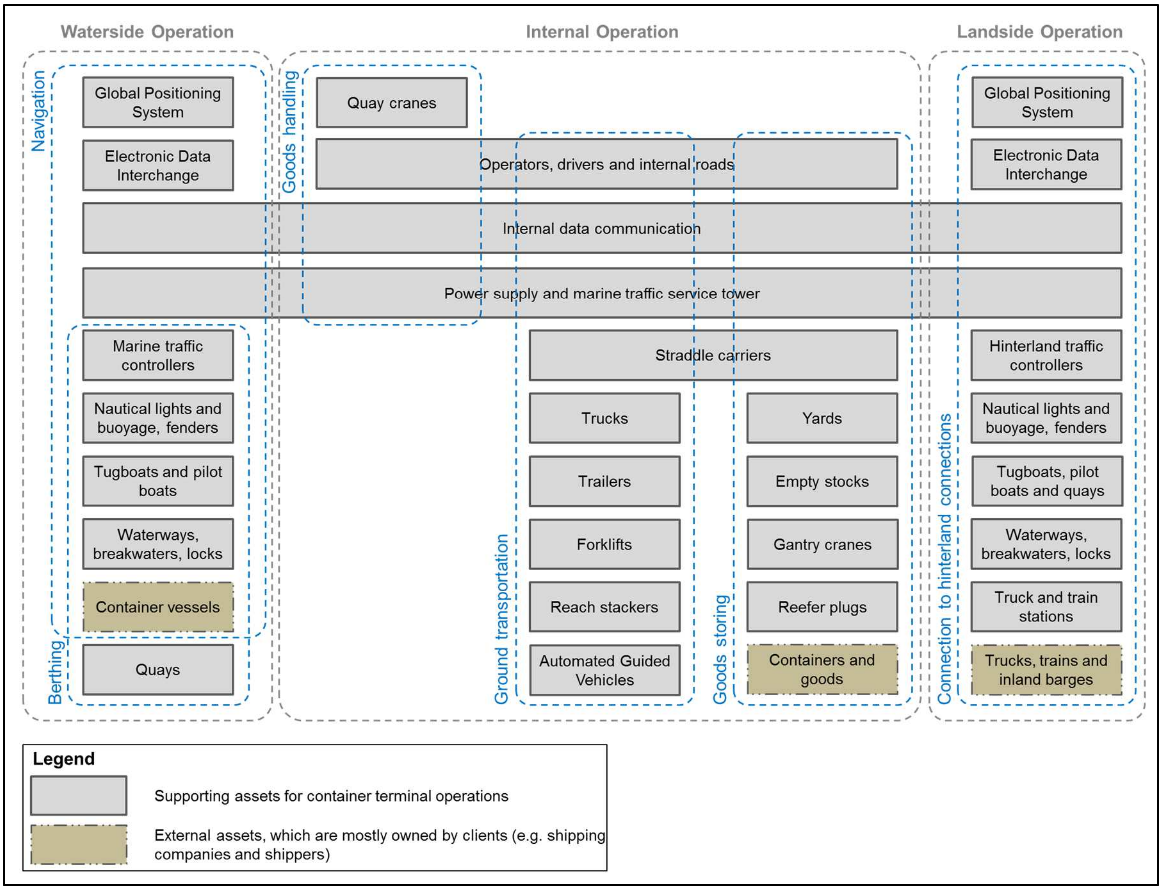

Figure 2-2: Assets at container terminals categorized into their sub-operations. Source: Author

Chapter 3 - Assessment of Climate Risks and Opportunities for Container Terminals

Climate change is underway and is likely to increase in terms of frequency and intensity over the upcoming decades (Stenek et al., 2011). As elaborated in Chapter 1.2, different ports across the globe face dissimilar climate risks and opportunities. For instance, ports located in low-lying coastal and delta areas are subjected to the increasing risk of seawater flooding. Meanwhile, other ports are situated in areas sensitive to tropical cyclones and typhoons, such as ports in Texas (FEMA, 2008) and Taiwan (Ou et al., 2002). Nevertheless, all ports are facing one thing in common, which is more frequent and more intense weather events, such as draught, storms and heat waves. The growing frequency and intensity of such events are projected to occur around the world, although the degrees may vary from region to region (Stenek et al., 2011).

In this chapter, an overview of the observed and potential impacts of climate change and adverse weather events on container terminals is firstly presented. The impacts are mainly identified from the reviewed literature. The second half of the chapter is dedicated to describe the development of a climate risks and opportunities assessment matrix for container terminals. The matrix, which was constructed based on the recognized impacts, aims to identify (1) the significant climate risks and opportunities for a particular terminal and (2) the assets susceptible to the risks and hence require sufficient climate adaptation.

3.1 Current and Potential Climate Change Impacts on Container Terminals

The impacts of climate change on container terminals can be classified as direct and indirect ones. On one hand, direct impacts include effects that directly influence the operational, financial, environmental and social performances of the terminals, both negatively and positively. On the other hand, indirect impacts encompass effects on the global economy and commodities production, which could lead to either higher or lower terminal demand/call.

3.1.1 Direct Climate Change Impacts on Waterside Operation

The trend of rising sea level brings both opportunities and threats to container terminals around the world at the same time. Firstly, because of average sea level rise, the water depth and hence the draft clearance of waterways is likely to increase in all ports. In this case, the size of sea vessels that is accommodable by container terminals is expected to grow. Moreover, the rise can provide benefits to waterside operation as the dredging requirement might be lessened, which could further lead to lower marine traffic congestion, higher environmental performance and reduced operational expenditure for maintaining the waterways navigable. In contrast, average sea level rise would negatively affect the waterside operation of some terminals. The rising level of waterways may reduce bridge clearance and therefore might lessen the accessibility of container terminals whose waterways are situated behind bridges.

Apart from average sea level rise, the waterside operation could also be affected by more frequent and more intense precipitation, fogginess, snowfall and hail. All of them are expected to reduce the visibility in waterways and hence the marine safety. If the visibility drops to any level below the safety limit, the speed of incoming and outgoing sea vessels may have to be reduced, such that the flow of goods through container terminals could be slowed down. In case of extremely low visibility, the waterways would be closed for safety reasons, leading to higher terminal downtime. Also, extreme rainfall may induce higher volume of silts and debris run-off to waterways, such that the navigability of the waterways would be reduced and subsequently the dredging requirement could be raised.

Moreover, high winds, high waves and dust storms could reduce the marine safety, as well as the navigability and berthability of the incoming container ships. In extreme cases, as shown in Table 3-1, the waterways have to be closed, which causes higher terminal downtime and hence lower terminal revenue. They will also require ports to provide more extensive search and rescue supports if the number of marine traffic accidents is raised, such that their operational expenditures will be increased.

Table 3-1: Potential impacts of high winds on container terminal operations, adapted from Gaythwaite (2004, p. 62)[6]

Wind speed (m/s)	Effect on waterside operations	Effect on internal operations
Greater than 11.5	Berthing limit	Inoperative quay and gantry cranes
Greater than 17.5	Berthing and marine traffic limits	Idem
Greater than 24.5	Idem	Damage to quay cranes if they are not properly lashed
Greater than 56	Idem	Damage to quay cranes even if they are properly lashed

Further, longer and more intense drought could affect the waterside operation of inland container terminals negatively as it reduces the draft clearance of the waterways and therefore might raise the dredging requirement. During extreme drought period, the waterways may need to be closed for a long time period, leading to higher terminal downtime. Also, in some ports, higher maximum and lower minimum air temperatures are observed. On one hand, the rising global average air temperature may bring opportunities for ports situated in high latitude as their numbers of days of icy waterways could be reduced. On the other hand, the safety of navigation would be negatively affected by lower air temperature as icing/freezing rates of sea vessels and navigation equipment might be increased.

3.1.2 Direct Climate Change Impacts on Internal Operation

Strong wind driven by storms, cyclones and typhoons, as well as limited visibility induced by high fogginess and rainfall are considered to be two of the greatest challenges for goods handling and storing sub-operations. As shown in Table 3-1, during severe winds, cranes cannot be operated effectively, especially quay cranes, whose spreaders are very sensitive to winds. If their operations are maintained during such period, damage to containers being handled could occur. This would also lead to injury or even death of terminal labors working on the ground, especially if the containers fall down or are wrongly placed. Further, containers stored in stack formation in yards and empty stocks may collapse once the wind force exceeds the structural strength of the formation, which could cause damage to the containers and contained goods.

Heavy rainfall, snowfall, hail, as well as severe flooding induced by intense precipitation, storm events and average sea level rise would also directly interrupt the internal operation. Such events are likely to deteriorate goods storing areas, terminal assets and stored goods that are not resistant to water (Scott et al., 2013). Moreover, during those events, ground vehicles could not be operated in a timely and efficient manner, such that the internal operation would be disrupted or even halted. Furthermore, higher and lower air temperatures would increase the cooling and heating demands for reefers and goods in need of heating, respectively. In these cases, (1) the operational expenditures for goods storing and (2) the greenhouse gas emissions from terminal operations would increase, which also lead to lower terminal profits and reduction in the environmental performances of the terminals, respectively (Connell et al., 2015).

3.1.3 Direct Climate Change Impacts on Landside Operation

Climate change may also negatively impact the connection of container terminals to their hinterland connections. If the connection is severely damaged, the reputation and attractiveness of the terminals would be reduced and so does the terminal demand/call. Increasing road surface temperature, extreme rainfall and more intense lightning might soften road pavement, weaken railway structures and could negatively affect the operation of hinterland transporters (Scott et al., 2013). Moreover, more frequent and more intense precipitation and high winds may raise soil moisture level, reduce the slope stability and damage structural integrities of roads and railways. All of the impacts could negatively affect the connectivity of container terminals, such that the flow of goods through the terminals might be reduced.

[6] Different vessels and cranes have distinct thresholds of wind speed. Hence, the thresholds presented in Table 3-1 might not be directly applicable to all container terminals.

Further, although hinterland connections are not considered as one of the sub-operations of container terminals in this thesis, it should be noted that any impact on the connection is likely to affect the connectivity of the terminals. Ports depend heavily on certain hinterland connections. For instance, the operation of a newly constructed container terminal in Yangshan Port in Shanghai is reliant on the functioning of Donghai Bridge, which is the only connection between the port and centre of Shanghai. Because of its location, the bridge is very vulnerable to any potential storm in East China Sea. During such event, the bridge may have to be closed, which leads to disruption in goods flow from and to the port. If the bridge downtime is significantly high, the terminal demand/call might fall down as the goods flowing through the terminal would not be delivered to their final destinations on time.

3.1.4 Direct Climate Change Impacts on Critical Infrastructures

As shown in Figure 2-2, several assets are of great importance for all container terminal sub-operations. The assets, which can be considered as critical infrastructures for container terminals, comprise of (1) power supply, (2) internal data communication network and (3) marine traffic service tower. Disruption in any of them would lead to terminal closure as all of the operations could not be performed. As an example, flooding in power station, very high precipitation, strong winds, intense lightning and heat waves could lead to failure in power supply, such that all electrical equipment are inoperable. Moreover, flooding and other extreme weather events can disrupt the functionality of marine traffic service towers or even may damage them. In these cases, employees whose jobs are to monitor and manage the flows of marine traffic would not be able to perform their functions well.

3.1.5 Direct Climate Change Impacts on Socio-environmental Performances of Container Terminals

Some climate change impacts could also affect the social and environmental performances of container terminals. Working accident induced by severe adverse weather events is one of the examples of negative effects of climate change on the social performance. Moreover, dust explosion, fire generation and reduction in air quality, which are mainly induced by climate change impacts on goods storing sub-operation, may deteriorate the health and well-being of terminal labors and residents living nearby the terminals. Further, reduction in the water quality because of higher dredging frequency and intensity may force those whose incomes are dependent on the water, such as fisherman, to migrate or search for new jobs.

Furthermore, run-off of dusts, silts and debris to waterways, as well as more frequent dredging activities reduce the water quality and hence threaten the habitats of marine vegetation and protected species around the terminals. Moreover, high waves, intense precipitation, sea level rise, higher sea surface temperature and increase in the salinity of seawater could negatively affect the habitability of mangroves, which present within or around waterways of some terminals situated in tropical region, such as in TMMeB and Port of Manzanillo. In some ports, such as in Port of Manzanillo, port stakeholders are responsible to maintain the vegetation and species living within their operational areas (Connell et al., 2015). Any failure in doing so would result in penalty and therefore higher expenditures.

3.1.6 Indirect Climate Change Impacts on Container Terminals

Climate change is very likely to impact the economy of a region and the distribution of global production of climate-sensitive commodities (Connell et al., 2015). For instance, long draught, rising air temperature and low precipitation would lead to higher crop failures and therefore less export of agricultural products by the affected regions. On one hand, if a terminal is very dependent on the export of those products, the terminal demand/call can be significantly reduced. On the other hand, if the crop failure rate is very high, the regions may have to start importing those agricultural products. This could be an opportunity for terminals whose main trading countries are capable of maintaining or even expanding their agricultural productions following the impacts of climate change as their terminal demands/calls could be increased.

3.2 Climate Risks and Opportunities Assessment Matrix for Container Terminals

To summarize the identified climate risks and opportunities for container terminals, as well as to allow one to perform first-scoping or quick-scan assessment for a particular terminal, a climate risks and opportunities assessment matrix for container terminals was developed, as partially presented in Figure 3-1[7]. In the matrix, the potential impacts of climate change and each adverse weather event on a container terminal are categorized into (1) operational, (2) financial, (3) environmental and (4) social risks and opportunities for the terminal[8]. Moreover, where possible and applicable, the thresholds of the relevant weather variables are presented for all adverse weather events and climate change impacts. Further, the main sub-operations and assets affected by them, as well as the possible primary and secondary impacts induced by the adverse weather events and climate change are clearly specified in the matrix. The impacts are explicitly separated such that the users could recognize which impacts are directly caused by adverse weather events and climate change (i.e. primary impacts) and which ones are the consequences of occurrence of the primary impacts (i.e. secondary impacts).

Next to the columns of both primary and secondary impacts, additional columns of *Expected Impact* are provided to allow the users to assess the climate risk and opportunity profiles of their terminals. In the matrix, the expected impacts are classified into (1) *N/A – Not applicable, (2) Opp – Opportunity*, (3) *L – Low risk*, (4) *M – Medium risk* and (5) *H – High risk*. The first category can be applied whenever a climate change effect or adverse weather event is irrelevant to a terminal performance indicator. Moreover, the second class is suitable for an effect or event that may contribute to an indicator positively. Further, the proposed categorization of risk magnitudes is appropriate for an effect or event that could affect a performance indicator negatively.

As climate risk tolerances in different terminals could vary, it is recommended that the relevant stakeholders are consulted to determine the appropriate range of each risk magnitude. In this case, their tolerances can be incorporated into the assessment, such that its effectiveness could be enhanced. An example of guidelines to determine the appropriate magnitudes of climate risks for different terminal performance indicators is presented in Table 3-2. The table shows the range of each risk magnitude employed for climate risks assessment for Port of Manzanillo by Connell et al. (2015).

Table 3-2: An example of classification of climate risk magnitudes for ports. Source: Connell et al. (2015, p. 303)

Magnitude	Expected impacts			
	Operational (Proxy: Annual port downtime)	Financial (Annual revenue of port operations)	Environmental (Environmental impacts)	Social (Social impacts)
L	< 1% increase	< 1% reduction	Negative, minor, reversible	
M	1 – 10% increase	1 – 5% reduction	Negative, medium, irreversible, temporary	
H	> 10% increase	> 5% reduction	Negative, major, irreversible, long-term	

As shown in Table 3-2, in general, climate risks for the environmental and social indicators are qualitatively assessed. Therefore, environmental and social impact assessments could be performed to determine the appropriate risk/opportunity magnitudes of all climate change effects and adverse weather events for both indicators. In contrast, the magnitudes for the operational and financial indicators are quantitatively measured. The expected impacts of each climate risk on the operations of a terminal can be estimated by considering (1) the anticipated duration of the associated adverse weather event in a year and (2) the expected reduction in the operability of the terminal during the event. For instance, if an event is anticipated to occur for 10% of the annual operation time and it has a 50% chance for halting the operations, the expected increase in the *annual terminal downtime* can be approximated as 5%.

[7] The complete assessment matrix is presented in Appendix C.
[8] Operational risks and opportunities include those that potentially affect the operations of the terminal. Financial risks and opportunities encompass those that could influence the financial performance of the terminal. Environmental risks and opportunities include those that are likely to reduce and enhance the environmental performance of the terminal, respectively. Social risks and opportunities include those that might affect the social performance of the terminal.

Climate Risks and Opportunities Assessment Matrix for Container Terminals

Name of Assessed Terminal: Terminal A

No	Weather Event and Impact of Climate Change	Main Type of Risk/Opp. for Terminal*	Main Sub-operation Affected	Relevant Asset(s)	Range/Threshold of Relevant Weather Variables: Variable	Range/Threshold of Relevant Weather Variables: Range/Threshold	Risks and Opportunities	Risk for Terminal Assets/Operations?: Assets	Risk for Terminal Assets/Operations?: Operations	Expected Impact**	Other Sub-operations Affected	Relevant Secondary or Compound Effects: Risk/Opp. Type*	Relevant Secondary or Compound Effects: Risks and Opportunities	Expected Impact**	Source
1	Impacts of climate change on the economies of the terminal's main trading countries	FIN	All	None	N/A	N/A	• Lower terminal demand/call due to (1) reduction in the production of main export commodities in the regions served by the terminal, such that the export volumes of the regions are lessened and/or (2) increase in the production of main import commodities in the main trading countries, such that their demands for import are reduced. • Higher terminal demand/call due to (1) increase in the production of main export commodities in the regions served by the terminal, such that the export volumes of the regions are enhanced and/or (2) reduction in the production of main import commodities in the main trading countries, such that their demands for import are enhanced.	-	√	L	All	None	None	N/A	Connell et al. (2015), Stenek et al. (2011), USCCSP (2008)
2	High salinity of seawater	ENV	None	Aquatic vegetations and species	ΔSeawater salinity	> 0 ppm	• Reduction in the habitability of the vegetations and species due to salt stress.	√	-	L	None	FIN	• Higher expenditure for compensating the loss of the vegetations and species. • Higher premium to insure the vegetations and species.	N/A	Connell et al. (2015), Stenek et al. (2011)
3	Droughtness [only for inland container terminals]	OPE	Navigation and Connection to hinterland connection	Waterways	ΔWater level	< 0 cm	• Slower marine traffic/Higher terminal downtime as a portion of waterways could be closed during dredging, which is more frequently needed. • Reduction in size of sea vessels accommodable due to higher restriction in ship navigability. • Lower volume of goods served by the terminal due to reduction in the amount of cargos that can be carried by incoming vessels. It has been estimated that a cargo vessel must reduce its carrying load by 50 - 270 tons for every 2.5 cm decline in the water level. • Increase in terminal downtime during drought or dry period.	√	√	N/A	All	OPE	• Inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.	N/A	Stenek et al. (2011)
												ENV	• Off-site and water pollutions due to dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and hence reduction in water quality.	N/A	
												FIN	• Lower terminal profit due to slower marine traffic/higher terminal downtime and lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium due to higher dredging costs. • Higher operational expenditure/insurance premium for compensating the loss of the vegetations and species.	N/A	
												SOC	• Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.	N/A	
4	High wind, including that induced by storm	OPE	Goods handling	Quay cranes	Wind speed	> 11.5 m/s (Inoperativeness)	• Reduction in the operationality of quay cranes. • Lower volume of goods served by the port due to slower internal operation/higher terminal downtime. • Damage/loss of quay cranes and goods being handled in case of any goods handling accident or extreme winds.	-	√	H	All	OPE	• Slower/inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.	H	Connell et al. (2015), Gaythwaite (2004), Scott et al. (2013), Stenek et al. (2011)
						> 24.5 m/s (Damage to quay cranes if they are not lashed properly)		√	-	M		FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance requirements for the affected quay cranes and goods. • Higher operational expenditure/insurance premium for replacements of the damaged quay cranes and goods.	M	
						> 56 m/s (Damage to quay cranes even if they are lashed properly)		√	-	L		SOC	• Injury and death of port labors in case of any severe winds or goods handling accident.	N/A	

*OPE = Operational; FIN = Financial; ENV = Environmental; SOC = Social

**List of input parameters:

Magnitude	Description	Impact
N/A	No risk/opportunity or the risk/opportunity type is irrelevant	
L	Low risk	Operational: < 1% increase in annual terminal downtime Financial: < 1% reduction in net annual terminal profit Environmental: Minor and reversible impacts on vegetations, birds, species, air and water qualities Social: Minor and tolerable impact on port labors and society
M	Medium risk	Operational: 1% - 10% increase in annual terminal downtime Financial: 1% - 5% reduction in net annual terminal profit Environmental: Medium and irreversible, but temporary impacts on vegetations, birds, species, air and water qualities Social: Medium, temporary and tolerable impact on port labors and society
H	High risk	Operational: > 10% increase in annual terminal downtime Financial: > 5% reduction in net annual terminal profit Environmental: Major, irreversible and long-term impacts on vegetations, birds, species, air and water qualities Social: Major, long term and intolerable impact on port labors and society
Opp	Opportunity	Operational: Lower annual terminal downtime Financial: Increase in net annual terminal profit Environmental: Enhancement in the habitability of vegetations, birds, species, as well as increase in air and water qualities Social: Positive impact on port labors and society

Figure 3-1: An example of a filled out partial climate risks and opportunities assessment matrix for container terminals. Source: Author

Furthermore, for the expected impact of each climate risk on the financial performance indicator, the author argues that *net annual cash flow from terminal operations* is a more appropriate proxy than the *net annual revenue*. This is mainly because the former also accounts for both (1) the potential increases in the expenditures of a terminal as a result of climate change and adverse weather events and (2) the liquidities of the port authority and/or terminal operators, which have to be maintained to ensure their abilities to pay their financial obligations when they fall due.

The expected effect of each climate risk on the *net annual cash flow from terminal operations* can be estimated by evaluating the potential impacts of the relevant adverse weather event on (1) the terminal revenue and (2) the capital and operating expenses of the terminal. The former can be computed as a product of (1) the annual revenue of the terminal in absence of any climate risk materialization and (2) the expected percentage reduction in the annual volume of containers served by the terminal as a result of the occurrence of the risk, while the latter can be assessed as a product of (1) the anticipated frequency of the event occurrence within a year and (2) the expected increases in the capital and operating expenses once the event takes place. The sum of the expected reduction in terminal revenue and the potential increases in the capital and operating expenditures is a good approximation of the expected impact of the risk on the financial indicator, although the factors of taxation, depreciation and termination values of assets are not considered in this way. If they are found significant by terminal stakeholders, they should be incorporated into the evaluation.

The outcomes of the assessment matrix include not only climate risks and opportunities significant for each container terminal, but also the sub-operations and assets vulnerable to the risks and hence require adequate climate adaptation. In this way, the users could identify climate adaptation measures for their terminals effectively. The currently proposed adaptation measures for container terminals are presented in Chapter 4.

Chapter 4 - Existing Climate Adaptation Measures for Container Terminals

As described in Chapter 3.2, after the significant climate risks in a particular container terminal are identified, effective and feasible climate adaptation measures for the terminal can be determined in an enhanced manner. Several literatures, in particular Connell et al. (2015), Ng et al. (2013), Scott et al. (2013) and Stenek et al. (2011), have discussed the potential adaptation measures for ports. They were reviewed and become the basis for this chapter, which serves as a summary of the currently available climate adaptation measures for container terminals. Therefore, this chapter could assist the users of the assessment matrix presented in Chapter 3.2 for exploring the potentially effective and feasible climate adaptation measures for their terminals.

4.1 Classification of Climate Adaptation Measures for Container Terminals

The currently proposed climate adaptation measures for container terminals can be classified into five categories, as presented in Table 4-1. According to Solecki (2013), grey/hard measures mostly require extensive assessments because of their significant financial, environmental and social costs. Conversely, green/soft measures are more beneficial from the environmental perspective as they are able to not only perform climate adaptation function but also provide ecosystem service. This is because they mostly provide open space and habitats for diverse wildlife (Solecki, 2013).

Table 4-1: Classification of climate adaptation measures. Source: Connell et al. (2015) and Solecki (2013)

Adaptation measure category	Description
Grey/hard/engineering measure	Development of structural solutions aimed for mitigating climate risks and/or extracting benefits from opportunities provided by climate change.
Green/soft/nature-based measure	The employment of biodiversity and ecosystem services to adapt to the impacts of climate change.
Hybrid measure	The combination of grey and green measures.
Building adaptive capacity	Enhancement in understanding and responding to climate change impacts.
Operational measure	Changes in operational processes and procedures to adapt to climate change.

While grey, green and hybrid measures can be thought of as physical measures, both building adaptive capacity and operational measures rather influence the governance, organization and operations of container terminals (Connell et al., 2015). On one hand, the strategies of building adaptive capacity mainly comprise of (1) measures to obtain and disseminate new information (e.g. monitoring and collecting data of the relevant weather variables, analyzing the observed and potential climate change impacts based on the extracted data and raising climate change awareness among port stakeholders), as well as (2) measures to support the governance and/or organizational structures of container terminals. On the other hand, operational measures include all adaptations that alter the operational procedures of the terminals. As elaborated in Connell et al. (2015), building adaptive capacity and operational measures are mostly no/low regret[9] and low cost adaptation options for ports. Therefore, it is highly recommended to implement them as soon as possible because they are very likely to support the effective execution of grey, green and hybrid adaptation measures at a later stage.

[9] No regret adaptation measures refer to those that deliver net benefits now and in the future, while low regret adaptation measures are those with relatively low costs and potentially large benefits under a wide variety of possible future climate scenarios.

4.2 Summary of Existing Climate Adaptation Measures for Container Terminals

In this section, examples of the currently recommended climate adaptation measures for container terminals are described. A large portion of the measures presented in the literature are those aimed to mitigate climate risks from the major adverse weather events in container terminals, including (1) seawater, groundwater and river flooding, (2) high precipitation, (3) high winds and (4) high air temperature. Table 4-2 lists possible measures against flooding and high rainfall that have been recommended for container terminals, especially those vulnerable to inundation. Moreover, as previously discussed, terminal assets and operations could be affected by high winds and hot weather events. Some potentially effective adaptation measures to deal with adverse winds and extreme heats are presented in Table 4-3 and Table 4-4, respectively.

Table 4-2: Examples of climate adaptation measures towards flooding and high precipitation risks for container terminals. Source: Connell et al. (2015), Ng et al. (2013), Scott et al. (2013) and Stenek et al. (2011)

Adaptation category	Measure
Grey	• Upgrade drainage system to increase the maximum water storage capacity and handle increasing water flow. • Raise the height of terminal infrastructures vulnerable to flooding. • Develop a new dock gate system to prevent flooding by retaining rainwater and storm water. • Raise the drainage system to prevent seawater ingress. • Retrofit assets susceptible to flooding and rainfall. • Upgrade and enhance sediment traps.
Green	• Implement landscape-based water catchment strategies to reduce the risk of drainage overflow. • Grow or re-generate natural drainage corridors (e.g. mangroves in tropical areas).
Hybrid	• Employing sustainable drainage systems for accommodating higher rainfall.
Building adaptive capacity	• Engage terminal stakeholders to plan landscape-based flood management strategies. • Review early flood warning systems as a preparation for more intense storm and rainfall. • Review flood response plans to prepare for sea level rise and rising precipitation trend. • Monitor sediment levels in waterways.
Operational	• Undertake review and adjust maintenance program for drainage system to ensure that the capacity of the drainage is always sufficient to cope with extreme rainfall and storm events. • Upgrade dredging programs and schedules to meet the increasing need for dredging. • Review and adjust the frequency of cleaning sediment traps to maintain their efficiencies. • Implement traffic management measures to minimize bottlenecks during extreme flooding. • Store perishable cargos and assets in areas less susceptible to flooding. • Account for higher precipitation and sea level rise when replacing or upgrading port infrastructures and superstructures.

Table 4-3: Examples of climate adaptation measures towards high winds for container terminals. Source: Connell et al. (2015), Stenek et al. (2011), van den Bos (2011)

Adaptation category	Measure
Grey	• Appropriately lash quay and gantry cranes to the ground during high wind events. • Develop or enlarge closed systems for goods handling.
Building adaptive capacity	• Assess the need to improve the braking systems of cranes. • Evaluate the need to enhance wind speed monitoring and prediction systems. • Continuously monitor wind speed and direction, as well as map paths of cyclones.

	• Monitor responses of sea captains, terminal operators, industries and customers to navigation, berthing and goods handling restrictions during high wind events. • Review contingency plans for delays and closure of goods flow caused by reduced and eliminated navigability of waterways.
Operational	• Employ active mooring systems whenever sea and swell conditions are difficult for berthing. • Use lashed container stack as a roughness increasing obstacle to avoid stacked containers from collapsing during high winds. • Alter work regimes whenever high wind speed is experienced. • Situate cranes in the shadow of high buildings whenever possible to avoid operational disruption from strong winds. • Rotate orientations of cranes appropriately to reduce the influence of dominant wind direction. • Review operating wind speed thresholds for goods handling equipment (e.g. quay cranes). • Embed potential impacts of rising peak of wind speed into the maintenance and replacement schedules. • Review the need to upgrade sub-systems and components of cranes as a result of rising wind speed. • Reduce the container stack heights in yards and avoid empty stock areas during high winds. • Perform assessments of ships navigability and berthability to understand the relevant wind speed thresholds, such that the navigation safety can be enhanced. • Review and strengthen dust suppression measures.

Table 4-4: Examples of climate adaptation measures towards hot weather events for container terminals. Source: Connell et al. (2015), Scott et al. (2013) and Stenek et al. (2011)

Adaptation category	Measure
Grey	• Upgrade energy efficiencies of freezers and air-conditioning systems.
Building adaptive capacity	• Conduct energy audits regularly to analyze the impacts of rising air temperatures and consider opportunities for reducing energy consumption based on the outcomes of the audits. • Ensure that the terminal community is notified when the risk of dengue and equivalent virus outbreaks is high and promote the use of mosquito repellents. • Review early warning systems for dengue and virus outbreaks. • Regularly monitor weather forecast and issue heat warning once the air temperature is expected to exceed the acceptable working temperature. • Provide guidelines on recommended actions to reduce the negative impacts of heat waves.
Operational	• Pass on energy bills for cooling reefers to customers/clients. • Deploy hot weather policy, in which the working hours of terminal labors are reduced or shifted to late hours during extremely hot days.

4.3 Determining Effective and Feasible Climate Adaptation Measures for Container Terminals

Based on the reviewed literature, it appears that climate adaptation options for ports have been discussed in detail in the scientific community. Moreover, several port stakeholders have developed climate adaptation plans for their ports. Therefore, the users of climate risks and opportunities assessment matrix presented in Chapter 3.2 could partially identify potential measures for their container terminals by exploring relevant literature of climate adaptation in ports and learning from climate adaptation plans and/or practices in terminals that share similar climate risks. Afterwards, an in-depth engineering study for adapting a terminal to climate change is required to explore for additional potential adaptation measures and assess the feasibility of each identified measure.

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Part III

A Methodology for Evaluating the Viability and Efficiency of Climate Adaptation Investments in Ports

Chapter 5 - A Framework for Assessment of the Viability and Efficiency of Climate Adaptation Investments in Ports

After acknowledging the significant climate risks, their potential impacts, as well as the effective and feasible climate adaptation measures for a port, the risks have to be valued in monetary terms. Without valuing the risks, it would be impossible to assess the viability of investments in the measures and to identify the efficient investment option for adapting the port to climate change. In this chapter, the development of an assessment framework for conducting such evaluation is elaborated.

The chapter begins by discussing the potential of Weather Value at Risk (Weather-VaR) for valuing climate risks into a port business model. Afterwards, the possible contributions of Real Options Analysis (ROA) for (1) assessing the viabilities of different climate adaptation investment options for the port and (2) estimating the efficient one by taking into account the uncertainty in future climate are discussed. In the end, a methodological proposal for approximating the financial viabilities and efficiencies of different climate adaptation options in a port is presented. As described in Chapter 1.5, a case study on Terminal Maritimo Muelles el Bosque (TMMeB) was conducted to enhance the originally developed assessment framework. However, to maintain the flow of this thesis, in this chapter, the final, improved framework is presented instead of the initial one.

5.1 Monetary Valuation of Climate Risks in Ports by Weather Value at Risk

Weather-VaR is a method that combines (1) the probability of occurrence of adverse weather events and (2) the sensitivity of a financial parameter to such events (Prettenthaler et al., 2016; Toeglhofer et al., 2012). The method allows Value at Risk concept, which is widely employed in financial sector for assessing the expected loss of an investment portfolio, to be applicable for valuing climate risks into the financial performance of a weather-sensitive business sector.

In Prettenthaler et al. (2016) and Toeglhofer et al. (2012), Weather-VaR is defined as the maximum expected loss due to adverse weather events for a given level of confidence over a certain time period. The concept is illustrated in Figure 5-1, which depicts the probability density function of a financial parameter resulting from weather fluctuations. As indicated in the figure, Weather-VaR is currently interpreted such that it is dependent on the risk tolerance of the investors. For instance, if an investor can accept the impacts of any adverse weather event that has a chance of occurring of 5% per year, the corresponding Weather-VaR is the value of the appropriate financial parameter (e.g. *net annual cash flow*) at a confidence level of 95%.

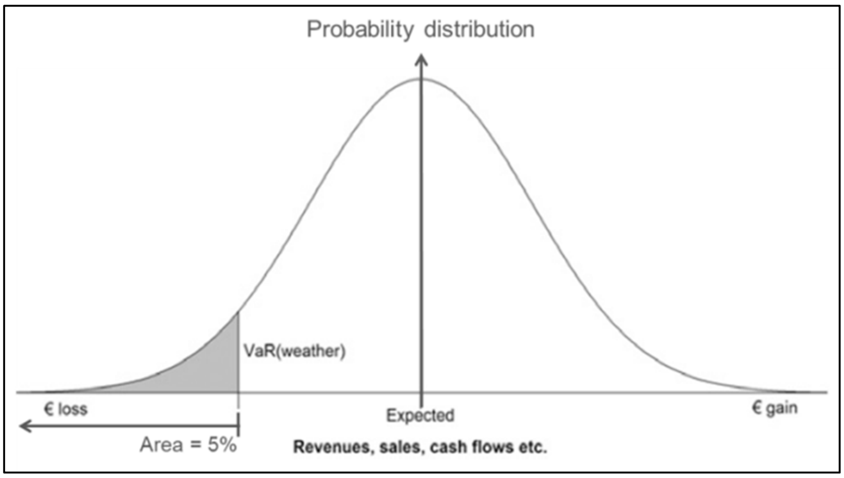

Figure 5-1: Weather-VaR at 95% confidence level, adapted from Toeglhofer et al. (2012, p. 193)

5.1.1 Steps in Weather Value at Risk

As previously described, Weather-VaR integrates (1) the probability of occurrence of adverse weather events and (2) the sensitivity of a financial indicator to such adverse events. Based on their analysis, Toeglhofer et al. (2012) recommend the following steps for applying the method effectively:

- **Step 1:** Identify a specific financial indicator that serves as a proxy for climate risks. Examples of potential indicators are the quantity of goods sold, revenue, net profit and net cash flow.
- **Step 2:** Determine weather variables that affect the indicator.
- **Step 3:** Describe the sensitivities of the financial indicator to fluctuations in the weather variables.
- **Step 4:** Describe the probability distributions of the weather variables.
- **Step 5:** Measure the Weather-VaR of the financial indicator at a given confidence level by consolidating the sensitivities and probability distributions identified from Steps 3 and 4, respectively.

In Prettenthaler et al. (2016) and Toeglhofer et al. (2012), the first step has been performed by analyzing the relevant business models. The second and third steps have been conducted using correlation and regression approaches, respectively, such that (1) the weather variables that significantly explain the variation in the indicator are identified and (2) the magnitude of the sensitivity of the indicator to each significant variable is known. The execution of the fourth step required the availability of historical data of the weather variables identified in Step 2. In Step 5, the regression model developed in Step 3 can be employed to estimate the values of the financial indicator in different weather conditions. By combining the values with their respective probabilities of occurrence, the Weather-VaR at a particular confidence level can be determined and expressed in monetary terms.

5.1.2 Compatibility of Weather Value at Risk with Port Operations

From the description of Weather-VaR, it was tempting to apply the method into port operations directly as it allows climate risks to be valued in monetary terms and hence incorporable into port business models. However, before the method is employed for such purpose, its compatibility with port operations should be firstly examined. The assessment of the compatibility was conducted by evaluating the applicability of all steps into port operations.

The first step of determining the specific financial performance indicator of a port has been partially performed in Chapter 3.2, in which *net annual cash flow from port operations* was found to be the most suitable indicator for assessing the magnitude of each climate risk on the financial performance of a port. However, as each private operator in a landlord port holds a concession for not only a year, but a much longer time period (i.e. up to 50 years, according to Becker et al. (2012)), the *net present value (NPV) of all cash flows* during the concession is a better fit for Weather-VaR application. Furthermore, the second step, which requires an identification of various climate risks in port operations, could be conducted using the presented climate risks and opportunities assessment matrix in Chapter 3.2. The relevant port stakeholders can be consulted for filling the matrix. Also, archives of historical adverse weather events that affect the operations could be examined for ensuring the accuracy of the evaluation.

The third step can be performed as long as the impacts of adverse weather events on the *NPV of all cash flows* are known or can be approximated. For instance, the impacts of a certain sea level and wind speed on the cash flows can be assessed quite well. Firstly, any sea level above port infrastructures causes flooding, leading to (1) a reduction of *revenue* from port operations and (2) increases in its *capital and operating expenses* for reinstating the affected port assets and enhancing its operational procedures, respectively. Secondly, the higher the wind speed, the more difficult it is for crane operators to perform goods handling and storing sub-operations. Therefore, port operations are expected to be slower as the wind speed rises. In this case, the *revenue* would be declined. Moreover, during extreme wind events, cranes and stacked containers could fall down and get damaged. These events would raise the *capital and operating expenses* of the port for repairing or replacing the cranes and compensating the damaged goods to clients, respectively.

The fourth step, in which the probability of occurrence of adverse weather events is modelled and evaluated, is dependent on the availability of historical data of the significant weather variables. In practice, this step could be executed without any significant hurdle as marine traffic controllers generally have access to meteorological stations situated nearby their ports (PIANC, 2012b). Therefore, the sensitivity of the financial indicator to each significant weather variable can be combined with the probability of occurrence of the associated adverse weather events for performing the recommended last step of valuing climate risks in monetary terms.

However, before the proposed final step is conducted, the future projections of the significant weather variables should be developed to value climate risks in any future year within an appropriate assessment time frame. Once the future values are recognized, the potential impact of climate risks on the *NPV of all cash flows* can be evaluated using discounted cash flow analysis. The analysis takes into account the expected accumulation of interest, which is translated into the assessment discount rate. In the context of Weather-VaR application for valuing climate risks in ports, the rate can be used to discount future financial losses into their present values using the following equation:

$$Present\ Value = \frac{1}{(1+d)^t} * Future\ Value$$

, where d is the *discount rate* and t represents the number of years from the present. The first term is generally referred to as the *discount factor* for converting future values into the present ones. By summing all of the present values, the Weather-VaR of the impact of climate risks on the *NPV of all cash flows from port operations* can be evaluated.

5.2 Approximating the Viability and Efficiency of Climate Adaptation Investments in Ports

Once the significant climate risks are valued into a port business model in monetary terms, the financial viabilities and efficiencies of the feasible climate adaptation investment options for the port can be evaluated. This is because the *costs* of adaptation measures are directly comparable to the *benefits* offered. The *benefits* mostly consist of (1) *reduction in revenue losses* and (2) *mitigation of increases in capital and operating expenditures*. As the gained *benefits* are likely to last for an extended time period, applying discounted cash flow analysis is essential to assess the financial viabilities and efficiencies of different adaptation investment options.

In this regard, all future *benefits* and *costs* of each investment option can be transformed into their present values using an appropriate discount rate. The sum of all present values determines the *NPV of the option*. The decision rules of the assessment are based on the *NPV*, such that (1) if there is only one option being considered, one should proceed with it if its *NPV* is positive and (2) if there are multiple options being evaluated, then one should select the option with the highest *NPV*, given at least one of them generates positive *NPV* (Boardman et al., 2011). However, it is currently uncertain whether performing the measures at this moment will always be beneficial as the future climate is rather unknown and so do the benefits of adaptation. If climate change turns out to be lower than the previously expected, the measures would be financially unworthy.

Therefore, ROA is a suitable complement to Weather-VaR as it is capable of determining the financially viable and efficient investment option under the uncertain future developments. As described in Chapter 1.5, the spreadsheet analysis variant of ROA proposed by de Neufville et al. (2006), which simplifies the valuation of real options for engineering projects, was selected for assessing the viabilities and efficiencies of different investment options in adapting a port to climate change. The analysis mostly consists of three main steps, which are:

- **Step 1:** Develop a MS Excel spreadsheet that computes the *NPV of an investment option* to adapt a port to climate change based on the *costs* and expected *benefits* of the option in each year within the project lifetime.
- **Step 2:** Explore the implication of uncertain future condition on the *NPV* by considering different possible future scenarios. Each scenario leads to a different *NPV of the option*. The collection of *NPVs of the option* in

different future scenarios can be employed to determine (1) the *expected NPV of the option* and (2) the distribution of possible *NPVs of the option* taking into account the uncertain future climate. The *expected NPV* is simply defined as the average of all possible *NPVs*. Moreover, the variation in possible *NPVs* can be presented in a cumulative distribution function that documents the *Value at Risk of the option* at a certain confidence level. Similar to Weather-VaR, the *Value at Risk of the option* is defined as the lowest possible return on the investment option at the confidence level of the investor.

- **Step 3:** Analyze the contributions of other feasible investment options in adapting the port to climate change by altering the *costs* and expected *benefits* to reflect these options. The investment option with the highest *expected NPV* could be considered as the financially efficient one. Moreover, the *Value at Risk* of each investment option can be employed to describe its investment risk.

In fact, the proposed application of Weather-VaR described in Chapter 5.1 is interrelated to the first two steps of spreadsheet analysis because it assesses the potential impacts of climate risks on the *NPV of all cash flows from port operations*. As the reduction or elimination of the potential impacts are considered as the *benefits* of climate adaptation in ports, a MS Excel spreadsheet can also be developed for conducting the Weather-VaR analysis. In this way, Weather-VaR and ROA could be linked effectively for approximating the viable and efficient climate adaptation investment option for a port.

As spreadsheet analysis allows one to compute both the *expected NPV* and *Value at Risk* of each climate adaptation investment option, it can be employed for both optimization and regret-minimization objectives. On one hand, if a financer prefers to optimize its climate adaptation investment, the option that maximizes the *expected NPV* could be recommended as it is most likely to be the efficient one. On the other hand, if the financer prefers the regret-minimization approach, the appropriate investment options could be the ones with positive *Values at Risk*. This is because the probability of having investment loss can be reduced to the risk tolerance of the investor by doing so.

Based on these two rationales, in this thesis, the viable and efficient climate adaptation investment option for a port is operationalized as the one with the highest *expected NPV* among those with positive *Values at Risk*. If no feasible option has a positive *Value at Risk*, it can be concluded that adapting the port to climate change by any means will lead to an investment risk that is higher than the risk tolerance of the investor[10]. In contrast, an option with a positive *Value at Risk* implies that the risk of having negative return on the investment is smaller than his/her risk tolerance. Therefore, it could be considered as a viable one, although it can still lead to financial loss.

5.3 A Framework for Estimating the Viable and Efficient Options for Investing in Climate Resilient Ports

In summary, the combination of Weather-VaR and ROA has potential to enhance the effectiveness of decision making about (1) the financial viabilities of different feasible climate adaptation options for a port and (2) the financially efficient adaptation option for the port. Figure 5-2 shows a proposed framework for approximating the financially viable and efficient climate adaptation investment option in a port.

The first four steps exactly follow those recommended by Toeglhofer et al. (2012) for applying Weather-VaR method. However, as elaborated in Chapter 5.1, in order to incorporate climate change effects into the assessment effectively, two additional steps are required. The first addition is the generation of future scenarios of the relevant weather variables within an appropriate assessment time frame. In this way, climate risks in any relevant future year can also be monetarily valued. Afterwards, the recommended last step by Toeglhofer et al. (2012) is executed, in which (1) the sensitivities of *NPV of all cash flows from port operations* to the significant weather variables and (2) the probabilities

[10] In this thesis, the risk tolerance of the investor is defined as the acceptable chance of having loss on his/her investment. It should be employed to derive the confidence level for computing the *Values at Risk* of different investment options. As illustrated in Figure 5-1, the confidence level can be simply defined as (1 – Risk tolerance of the investor).

of occurrence of adverse weather events in the present and future are combined. In the end, the second addition of the determination of the assessment discount rate is suggested. This is because the rate is needed to convert the potential future costs of climate risks into their present values. In this way, the *Weather-VaR* in a port can be evaluated.

The subsequent two steps are grounded on the spreadsheet analysis variant of ROA. The eighth step is the identification of effective climate adaptation measures for a port and their costs in different adaptation options. This is directly related to the Steps 1 and 3 in spreadsheet analysis proposed by de Neufville et al. (2006), which requires the knowledge of potential *benefits* and *costs* of different options for adapting the port to climate change. In the end, the *expected NPV* and *Value at Risk* of each investment option are evaluated. As described in Chapter 5.2, the option with the highest *expected NPV* among all options that have positive *Values at Risk* could be regarded as the viable and efficient one for the port. Moreover, Figure 5-2 clearly specifies that Steps 2 – 9 should be repeated once shift in any influential weather variable occurs and/or additional knowledge about climate risks in the assessed port is obtained. Further, Steps 5 – 9 and Steps 7 – 9 have to be re-performed whenever changes in the appropriate time frame and discount rate are required, respectively. The re-evaluation step is highly recommended to ensure the accuracy of the recommendation for the viable and efficient climate adaptation investment option.

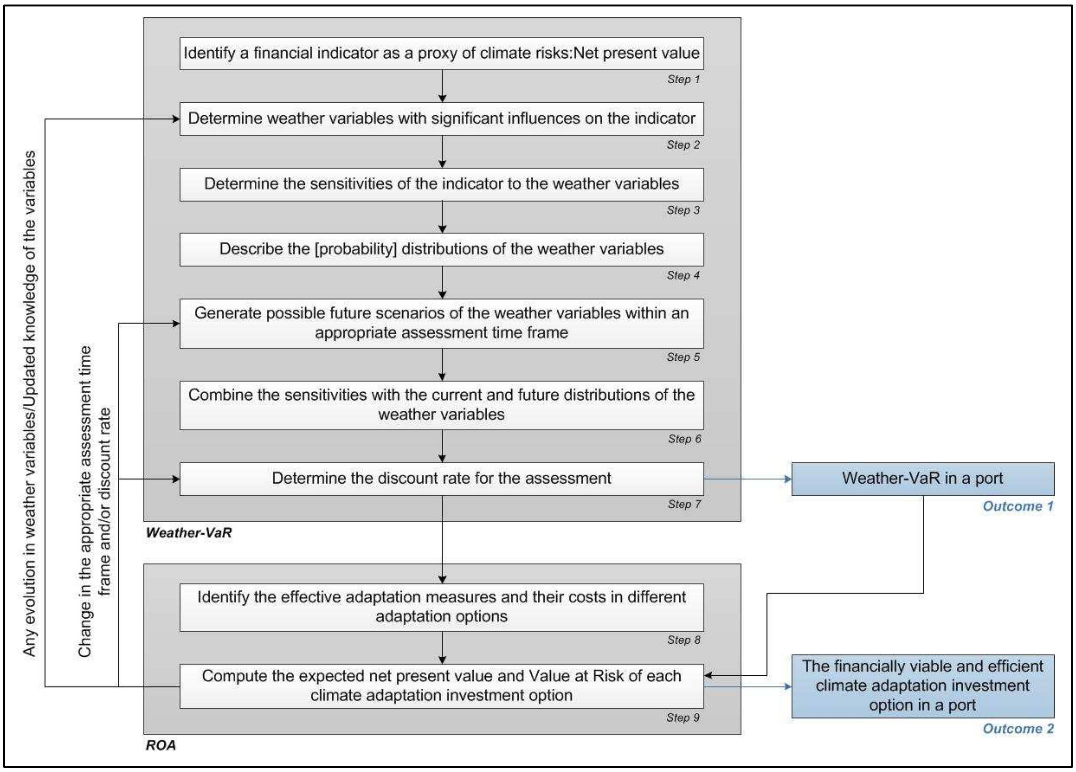

Figure 5-2: An assessment framework for estimating the financially viable and efficient adaptation option in a port

5.4 Incorporation of Non-Financial Impacts

Up to this section, only (1) financial impacts of potential adverse weather events and climate change on ports and (2) financial contributions of the effective climate adaptation measures for ports are discussed and considered. However, as stated in Ligteringen and Velsink (2012), in cost-benefit analysis of any port development project, the long-term social and environmental impacts should also be included. Moreover, as ports are of great importance for economies (Dwarakish & Muhammad, 2015), the economic loss induced by any adverse weather event in ports could be significant. The non-financial impacts of the events and the effective climate adaptation measures can be incorporated into the assessment using Social Cost-Benefit Analysis, which could translate them into monetary values. However, as discussed in Heinzerling and Ackerman (2002), the analysis is only appropriate if the non-financial impacts can be monetized with considerable accuracy and fairness. Although the usefulness and indispensableness of such an assessment is acknowledged, it is not part of the present study and is therefore not considered further in the research.

Chapter 6 - Case Study on Terminal Maritimo Muelles el Bosque

Stenek et al. (2011) have conducted a climate risks assessment for Terminal Maritimo Muelles el Bosque (TMMeB), a general cargo terminal in Cartagena, Colombia. The study has identified (1) the key climate risk that could negatively impact the terminal operations, (2) reduction in the terminal revenues and increases in its capital and operating expenses as a result of climate risks materialization, (3) effective climate adaptation measures for the terminal and (4) the costs of the measures.

Their analysis has also attempted to evaluate the viabilities of two different investment options in the measures. Nevertheless, their results could still be improved as they did not address several aspects with regard to climate adaptation in a port. First of all, they assumed that sea level rise, which turned out to be the key climate risk for the terminal, follows one of the two developed sea level projections (i.e. linearly and exponentially rising scenarios). However, as described in Church et al. (2014, p. 1181), the future sea level rise is rather uncertain and therefore the average annual sea level in TMMeB in the future can take up any value within a wide range of sea level. Therefore, the analysis has not incorporated the uncertainty about future climate sufficiently.

Secondly, their assessment did not consider various feasible adaptation options for the terminal as it only appraises two sets of adaptation options. The first set of options is to raise the causeway once by 600mm and 1,200mm in the beginning of the assessment time frame (i.e. 2010) under the linearly and exponentially rising sea level scenarios, respectively. These options can be considered as inflexible ones as the causeway is only raised once by a sufficient amount to cope with future sea level rise until the end of the assessment time frame (i.e. 2100). In the second set of options, which can be regarded as flexible ones, the causeway is elevated by 200mm three times and six times within the assessment time frame in the linearly and exponentially rising sea level scenarios, respectively. Based on the considered options, it could be further deduced that the assessment might have not addressed the issue of decision making under uncertain future climate as it simply assumes that the terminal stakeholders are knowledgeable about which future sea level scenario will actually occur.

In reality, based on the outcomes of the study of Stenek et al. (2011), COMPAS S.A, the private terminal operator, have invested in a climate adaptation of raising all terminal infrastructures vulnerable to seawater flooding by 1,500mm (Perez, e-mail communication, 2nd June 2016). As the adaptation level was considered more than sufficient to prevent TMMeB from seawater flooding until 2100, the implemented adaptation option could be thought of as an inflexible one. Even though the terminal has been protected against the risk of seawater flooding in practice, TMMeB case was still found appropriate to illustrate how the assessment framework developed in Chapter 5.3 contributes to viable and efficient climate adaptation investments in a port. Therefore, in the study, it was fictitiously assumed that no adaptation has been undertaken yet at the terminal. The outcomes of the fictitious case study will indicate whether other options could have also been considered. Furthermore, in order to maintain the coherency of this thesis, which demarcates ports as container terminals, the study was limited to the potential impacts of climate risks on the containers handling, transportation and storing operations in TMMeB.

To illustrate the potential contribution of the constructed framework presented in Figure 5-2, a majority of this chapter is dedicated for elaborating the application of the framework on the fictitious case of TMMeB. At first, an implementation of Weather-VaR method to value the significant climate risk into the terminal business model is presented. Then, the financially viable and effective adaptation option for the terminal is estimated using ROA. Afterwards, the results of sensitivity analysis of the recommended option to the key financial parameter and assumption are presented to discuss the robustness of the recommendation. In the end, the generalization of the framework is discussed based on the case study.

6.1 Weather Value at Risk in TMMeB

In this section, the outcomes of the application of the first seven steps in the proposed assessment framework are reported. As elaborated in Chapter 5.3, the steps are derived from Weather-VaR method to value climate risks into the terminal business model. Therefore, the *Weather-VaR* in TMMeB was expected to be the end-product of this assessment.

6.1.1 Step 1: Identify a Financial Indicator as a Proxy of Climate Risks in TMMeB

As discussed in Chapter 5.1, the *potential effect of climate risks on the NPV of all cash flows from TMMeB operations* is the most suitable indicator for this assessment. In Stenek et al. (2011), (1) the expected *annual revenue of TMMeB* from its containers-related operations from 2015 onwards, (2) the *financial values of TMMeB assets* susceptible to climate risks and (3) the *maintenance costs of the assets* vulnerable to the risks are reported. As they are components of *all cash flows from TMMeB operations* and they are sensitive to adverse weather events, *revenue of TMMeB* and *capital expenditures of TMMeB* were employed as the proxies.

Climate risks could impact them in two different ways. Firstly, they would disrupt the terminal operations, such that the *revenue of TMMeB* is reduced. Secondly, as the operator has to recover and/or replace the damaged assets following any adverse weather event, the additional maintenance and/or replacement costs are expected to raise the *capital expenditures of TMMeB*. To simplify this case study, the factors of taxation, as well as depreciation and termination values of assets are not considered. If they are later found significant by terminal stakeholders, they could be incorporated into the evaluation.

6.1.2 Step 2: Determine Weather Variables with Significant Influences on the Indicator

The analysis by Stenek et al. (2011) suggests that the impacts of seawater flooding are significant to TMMeB operations as it would reduce the *revenue of TMMeB* and raise the *capital expenditures of TMMeB*. Figure 6-1 presents the historical data of sea levels in TMMeB for the periods of 1951 – 2002 and 2006 – 2014, which was extracted from the database of University of Hawaii Sea Level Center (2016). It shows that the average annual sea level in TMMeB has a rising trend in the past.

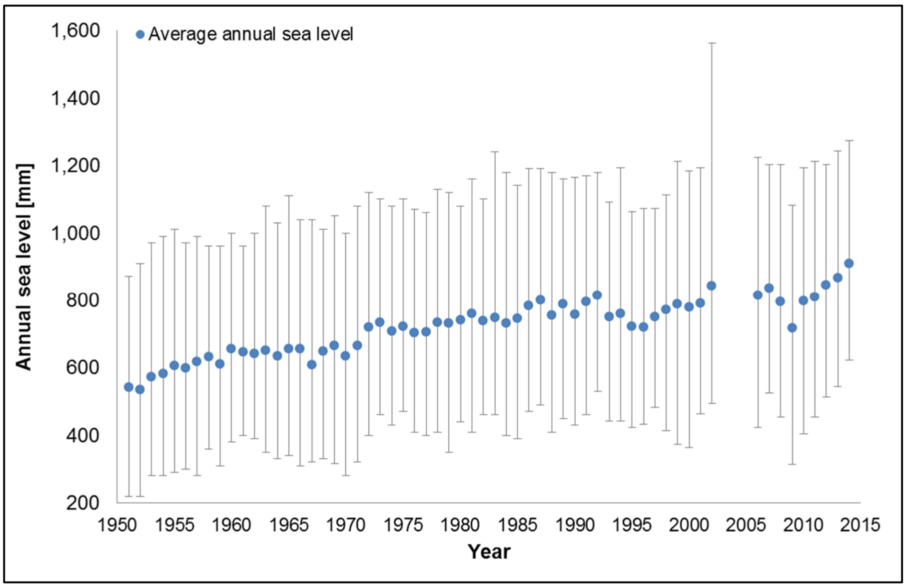

Figure 6-1: Historical data of sea levels in TMMeB[11]. Source of data: University of Hawaii Sea Level Center (2016)

Moreover, in the figure, blue dots represent the average sea level in each of the observed years, while the vertical bars represent the range of sea levels in a given year. The bars indicate that the sea level in TMMeB varies significantly in a

[11] The data for the period of 2003-2005 is not available in the database of University of Hawaii Sea Level Center (2016).

year. The variation is mainly contributed by (1) variation in astronomical tide (up to +/- 360mm of fluctuation), (2) seasonal variation (up to +/- 150mm of fluctuation) and (3) storm surges, whose impact varies from +80mm due to a storm event with 1-year return period to +170mm due to a storm event with 300-year return period (Stenek et al., 2011).

As shown in Figure 6-2, the terminal areas relevant to containers handling, transportation and storing consist of quay, island yard, causeway and empty stock. The last two regions were at high risk of seawater flooding as they were only about 400mm – 500mm above the expected average sea level in 2015, while the sea level at any time in a particular year can be up to 680mm higher than the average annual level. In fact, they had already been flooded for several days in 2002, which was perhaps caused by the combination of high tide, peak seasonal variation and a very rare storm event as the maximum sea level in that year was about 720mm higher than its average annual level. Figure 6-2 also depicts that the causeway is of great importance for terminal operations as it is the only route that connects the island and mainland areas. Therefore, the mobility of vehicles and goods within the terminal, and hence the *revenue of TMMeB* will be negatively affected if it is flooded.

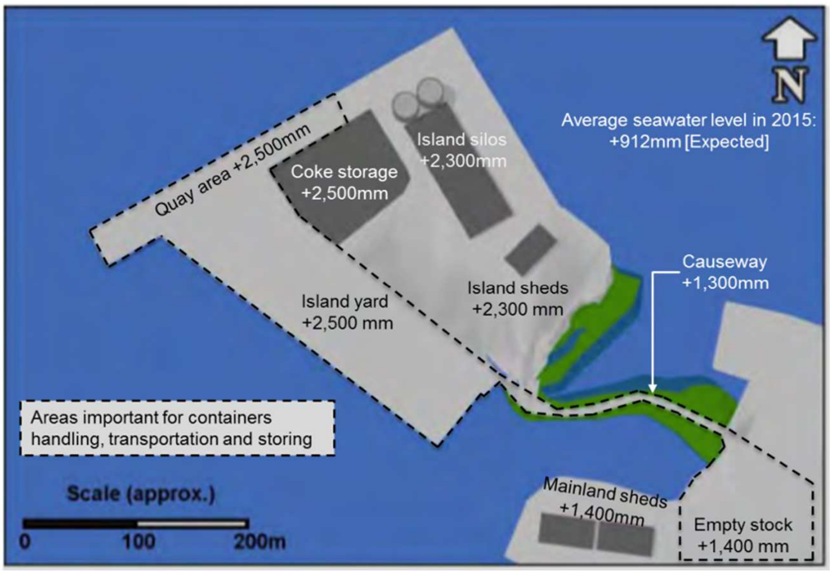

Figure 6-2: Topography of TMMeB before it was raised, adapted from Stenek et al. (2011, p. 58)

6.1.3 Step 3: Determine the Sensitivity of the Indicator to Seawater Flooding

The report by Stenek et al. (2011) has presented the financial consequences of seawater flooding. In this study, the consequences were slightly altered to classify them into (1) reduction in the *revenue of TMMeB* and (2) increase in the *capital expenditures of TMMeB*. First of all, it was assumed that the whole goods flow in TMMeB is halted whenever the causeway is flooded and hence the expected *revenue of TMMeB* during any flooding event is zero. From the projection of annual *revenue of TMMeB* from 2016 onwards described in Stenek et al. (2011), the impact of causeway flooding on the *revenue of TMMeB* in any year from 2016 to 2032 (i.e. the remaining concession period of COMPAS S.A.) was evaluated, as shown in Appendix D.1. In summary, based on two arbitrary assumptions of (1) TMMeB is operated for 24 hours a day and (2) the flow of containers is uniform throughout the day, the impact was expected to vary from USD 2,931 per flooding hour in 2016 to USD 4,703 per flooding hour in 2032[12].

Secondly, the increase in the maintenance costs of the causeway and hence the raise in the *capital expenditures of TMMeB* was unknown and therefore had to be estimated. In this study, it was supposed to be USD 35,000 per flooding event, which is equivalent to the monthly maintenance cost of the road during high precipitation period (Stenek et al., 2011, p. 69). But, in reality, the increase could be higher as a result of the saltwater intrusion into the causeway. In

[12] The *annual revenue of TMMeB* from containers handling, transportation and storing is expected to increase with an annual growth rate of 3% (i.e. from USD 25.7 million in 2016 to USD 41.2 million in 2032) (Stenek et al., 2011, p. 37).

order to account for this uncertainty, the factor was considered in the sensitivity analysis, which is later described in Chapter 6.3. However, the impacts of flooding in empty stock have not been reported in Stenek et al. (2011) and hence could not be incorporated into the case study. Therefore, the conducted analysis is likely to underestimate the potential impacts of climate risks on the financial performance of TMMeB.

6.1.4 Step 4: Describe the Distribution of Sea Level in TMMeB

As previously depicted in Figure 6-1, the distribution of sea level in TMMeB has a rising trend from year to year. Therefore, to determine the distribution in a particular year, the historical data of hourly sea levels in each observed year was normalized with respect to the corresponding average annual sea level. Figure 6-3 presents the distribution of the normalized data of hourly sea levels in TMMeB for the periods of 1951 – 2002 and 2006 – 2014. It indicates that the data is approximately normally distributed with a standard deviation of 123mm[13]. To capture the rising trend of sea level in TMMeB, the distribution was modified for the sake of the case study analysis. This was accomplished by simply shifting the distribution in Figure 6-3 such that the mean of the distribution matches the most recent average annual sea level or the expected average level in any year in the future, while the standard deviation was kept at 123mm.

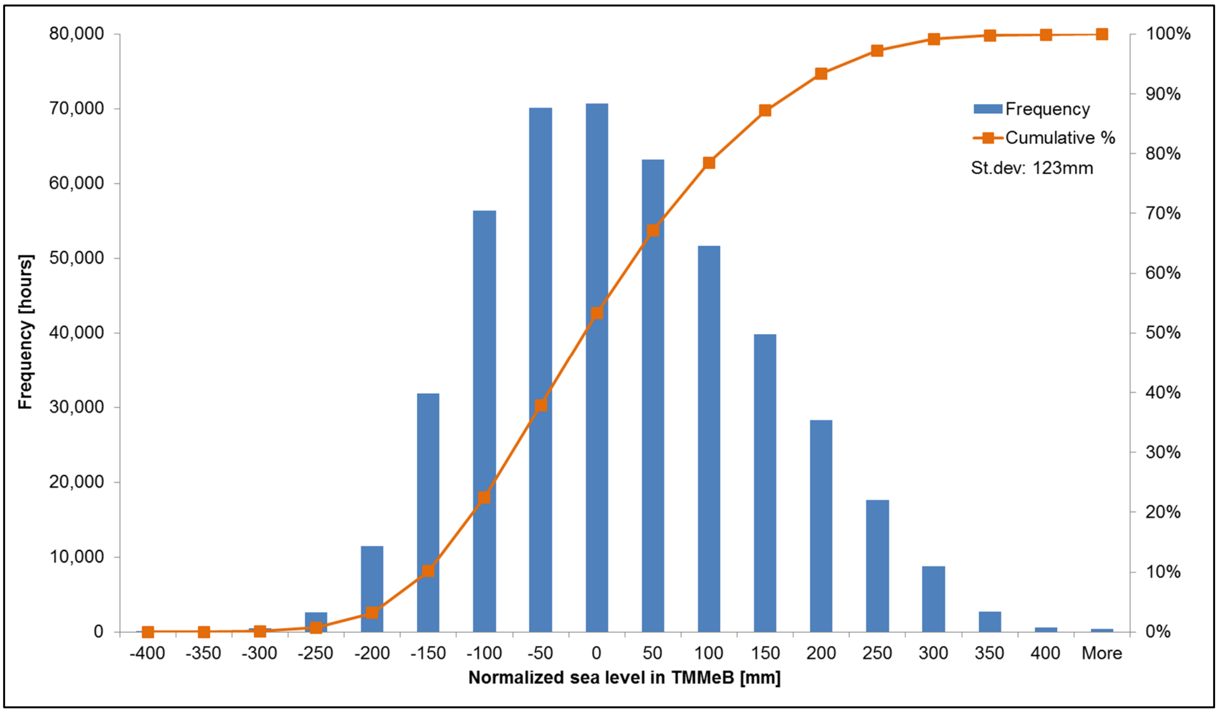

Figure 6-3: Histogram of the normalized sea levels in TMMeB from 1951 to 2014

6.1.5 Step 5: Generate Possible Future Scenarios of Sea Level in TMMeB

The sea level distribution in TMMeB in a particular year in the future is unknown and therefore several scenarios were needed to account for this uncertainty. In this study, projections of global mean sea level rise from 2000 to 2100 developed by the Intergovernmental Panel on Climate Change (IPCC) presented in Church et al. (2014, p. 1181) were employed to generate the required future scenarios of sea level in TMMeB. The interpolations of IPCC suggest that the average sea level in TMMeB in 2032, which was considered to be the appropriate assessment time horizon for this study taking into account the concession period of COMPAS S.A, will be within the range of 960mm – 1,022mm[14].

To ensure the quality of the cumulative probability distribution generated by ROA at a later stage, 120 scenarios of future sea levels in TMMeB from 2015 to 2032 were considered in the study. As presented in Figure 6-4, all of the

[13] A normal probability plot of the data is presented in Appendix D.2.
[14] The derivation of the range is presented in Appendix D.3.

scenarios were generated such that their average annual sea levels in 2032 are uniformly distributed between 960mm – 1,022mm. The lowest sea level rise scenario was developed such that it is linearly rising, while the rest of the scenarios were constructed as exponentially rising ones. In each scenario, the standard deviation of sea level distribution in TMMeB in a particular year was maintained at 123mm because the future sea level variance still cannot be projected with acceptable accuracy (Church et al., 2014, p. 1200). As a consequence, the potential increase in the deviation because of more intense and more frequent seasonal variation and storm events was not considered. Therefore, this study could underrate the *potential impact of climate risks on the NPV of all cash flows from TMMeB operations*. However, for the purpose of an illustrative case study, the simplified approach was deemed acceptable.

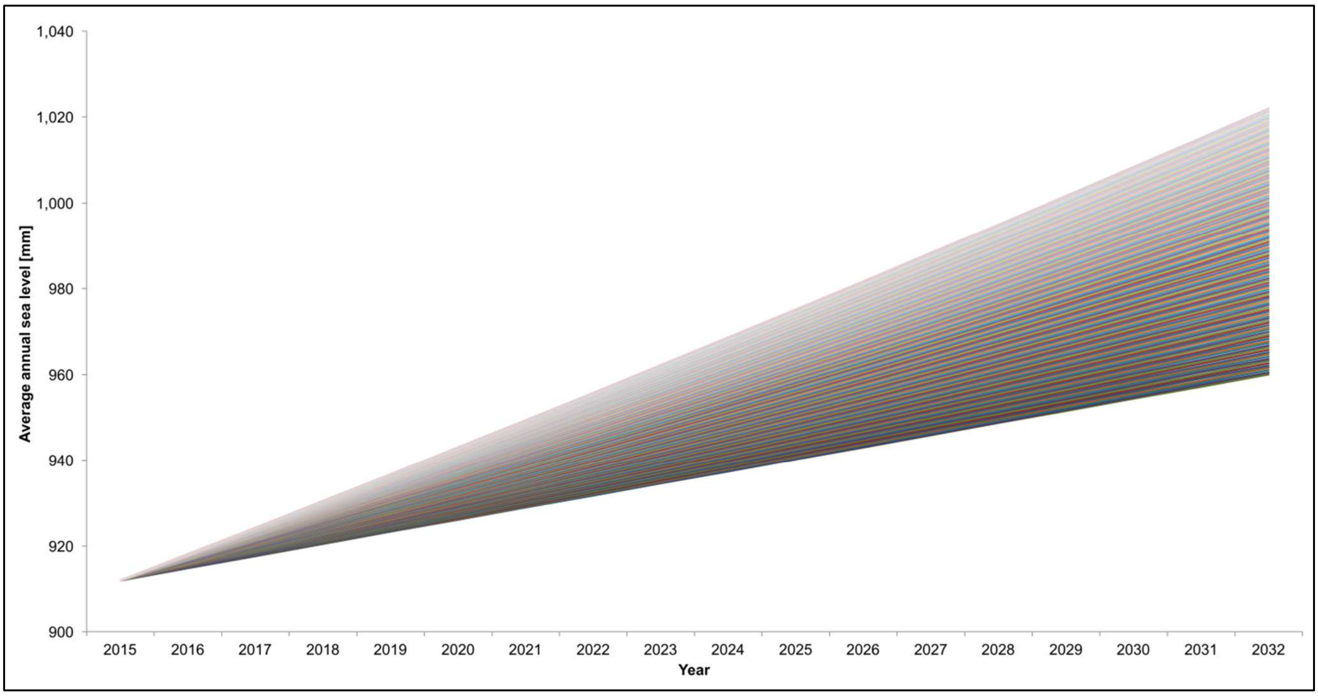

Figure 6-4: Scenarios of future sea level in TMMeB considered in the study

6.1.6 Step 6: Combine the Sensitivities with the Current and Future Sea Level Distributions

The financial value of climate risks in TMMeB in any year under each sea level rise scenario can be determined by combining (1) the sensitivity of *all cash flows from TMMeB operations* to seawater flooding and (2) the future sea level distribution in the terminal. At first, from the developed sea level distributions for all considered years under each scenario, the number of causeway *flooding hours* in each year can be evaluated. Afterwards, the number can be converted into the undiscounted *value of climate risks* using the following formula:

$$\begin{aligned} &Value\ of\ climate\ risks\ in\ a\ year \\ &\quad = -Flooding\ hours * Loss\ of\ revenue\ per\ flooding\ hour - Raise\ in\ capital\ expenditures \end{aligned}$$

The first term represents the reduction in the annual *revenue of* TMMeB, while the second term simply describes the increase in the *capital expenditures of TMMeB* due to causeway flooding. Both *loss of revenue per flooding hour* and *raise in capital expenditure* have been described in Step 3. In the computation, it was assumed that all flooding hours in a year are interconnected. Therefore, the *raise in capital expenditures* for recovering the causeway after it is flooded could be directly set to USD 35,000 per year. Such simplification was made as a result of the absence of detailed seawater modelling, which could estimate at which hours in a particular year are the causeway inundated. In practice, the flooding hours could be disconnected and hence the *raise* would be higher. In this case, the impact of climate risks on the financial performance of TMMeB would be more significant. As an illustration of the execution of Step 6, the calculation of *impacts of climate risks* in all considered years under both the lowest and the highest sea level rise scenarios is presented in Table 6-1.

6.1.7 Step 7: Determine the Discount Rate for the Assessment

As the terminal is operated by COMPAS S.A (Perez, e-mail communication, 2nd June 2016; Stenek et al., 2011, p. 7), the discount rate of the private operator was employed for the assessment. Stenek et al. (2011, p. 36) indicate that a *nominal discount rate* of 16% was employed by the operator for the terminal planning purpose. According to Stenek (e-mail communication, 13th May 2016), the *rate* was derived based on the weighted average capital cost of the operator, who was responsible for financing climate adaptation in TMMeB. In this case study, in order to effectively exclude the inflation factor, a *real private discount rate* was used. Based on DNP (2013, p. 7) and Stenek et al. (2011, p. 36), it could be estimated that the expected long-term inflation rate in Colombia is 8% per year[15]. Therefore, the *real private discount rate* was set at 8% per year[16].

Table 6-1 shows the calculation of the *impacts of climate risks on the NPV of all cash flows from TMMeB operations* under the lowest and the highest sea level rise scenarios. The computation indicates that the actual financial value of the risks was expected to fall within the range of –USD 1.52 million and –USD 0.80 million. By applying the same analysis under the other constructed sea level rise scenarios, a cumulative probability distribution of the *impact* was derived, as presented in Figure 6-5. Based on the distribution, by assuming a confidence level of 95%, the *Weather-VaR* in TMMeB was found to be approximately –USD 1.47 million. Or, in other words, the reduction of *NPV of all cash flows from TMMeB operations* would not exceed USD 1.47 million, unless any of the worst 5% of future sea level rise scenarios occurred.

Table 6-1: Examples of calculation of the potential impacts of climate risks in TMMeB

Year	Revenue loss/flooding hour	Discount Factor	Lowest Sea Level Rise Scenario			Highest Sea Level Rise Scenario		
			Flooding Hours	Impact of Climate Risks (2010 USD)		Flooding Hours	Impact of Climate Risks (2010 USD)	
				Undiscounted	Discounted		Undiscounted	Discounted
2016	2,931	1.00	7	-55,515	-55,515	8	-58,446	-58,446
2017	3,019	0.93	8	-59,150	-54,768	9	-62,168	-57,563
2018	3,109	0.86	8	-59,874	-51,332	11	-69,202	-59,329
2019	3,203	0.79	9	-63,823	-50,665	13	-76,633	-60,834
2020	3,299	0.74	10	-67,986	-49,972	16	-87,778	-64,519
2021	3,398	0.68	11	-72,373	-49,256	18	-96,156	-65,442
2022	3,499	0.63	12	-76,994	-48,519	22	-111,989	-70,572
2023	3,604	0.58	13	-81,858	-47,763	26	-128,716	-75,105
2024	3,713	0.54	13	-83,264	-44,985	31	-150,091	-81,089
2025	3,824	0.50	14	-88,536	-44,290	36	-172,664	-86,375
2026	3,939	0.46	16	-98,019	-45,402	42	-200,426	-92,836
2027	4,057	0.43	17	-103,967	-44,590	49	-233,787	-100,267
2028	4,179	0.40	18	-110,214	-43,768	57	-273,179	-108,483
2029	4,304	0.37	20	-121,079	-44,520	67	-323,364	-118,900
2030	4,433	0.34	21	-128,094	-43,611	77	-376,345	-128,131
2031	4,566	0.32	23	-140,019	-44,140	89	-441,378	-139,141
2032	4,703	0.29	24	-147,873	-43,163	104	-524,115	-152,984
Impact of climate risks on NPV of TMMeB (2010 USD)					**-806,259**			**-1,520,017**

[15] DNP (2013) suggests that the Colombian government is employing a *nominal social discount rate* of 12%, while Stenek et al. (2011, p. 36) describes that the *real discount rate* for the nation is 3.5%.

[16] *Real discount rate* is approximately equal to the difference between *nominal interest rate* and *inflation rate* (Boardman et al., 2011). Therefore, the appropriate *real discount rate* for climate adaptation investments in TMMeB is 8% (i.e. 16% - 8%).

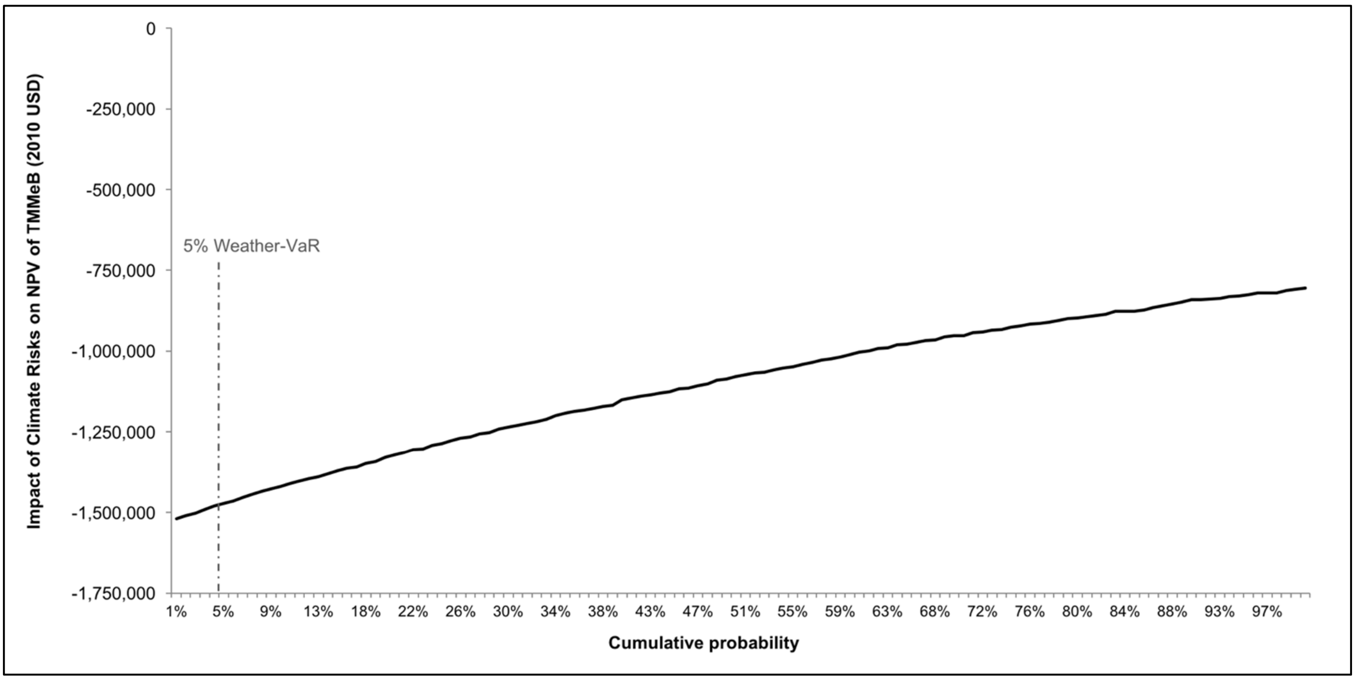

Figure 6-5: Cumulative probability distribution of impact of climate risks on Net Present Value of TMMeB

6.2 Estimation of the Financially Viable and Efficient Adaptation Option for TMMeB

6.2.1 Step 8: Identify Climate Adaptation Options for TMMeB and Their Costs

Based on the outcomes of the climate risks assessment conducted for TMMeB, Stenek et al. (2011) have proposed several adaptation measures for the terminal. The only relevant measure for containers handling, transportation and storing is raising the causeway. According to Stenek et al. (2011, p. 64), elevating the causeway requires *fixed* and *variable costs* of USD 30,000 and USD 50,000 per 100mm of increment, respectively. Moreover, the time needed to raise the causeway by 200mm was estimated to be a full operational day. The short construction time is explained by the fact that the causeway was just a dirt road and therefore it was relatively easy and low in cost to get elevated. The existence of retaining wall at the sides of the road allowed it to be raised through simple addition of material (e.g. gravel and asphalt), assuming the walls are of sufficient strength to support the weight of the added material (Stenek et al., 2011, p. 60). Because of this assumption, the author admits that the strategy of gradually raising the causeway using the proposed material addition technique might not be a sustainable solution for TMMeB. Nevertheless, the causeway has been raised by 1,500mm in practice using the method. Therefore, in this study, raising it up to an elevation level of 2,800mm was considered as a feasible adaptation solution.

Therefore, various adaptation options for the causeway could be considered. In this step, they were ranged from 100mm to 1,500mm with an increment of 100mm. The construction time required to raise the causeway was assumed to be linearly increasing with the adaptation level. For instance, the required time to raise the causeway by 100mm, 200mm, 300mm and 400mm were supposed to be 0.5 day, 1 day, 1.5 days and 2 days, respectively. As the causeway has to be closed during the construction, the reduction in the *revenue of TMMeB* during the closure was also considered as an addition to the *variable cost* of the adaptation. In reality, the relationship between the construction time and increment level is not necessarily a linearly proportional one. Nevertheless, such simplification was made because of the time limitation of this research. As a consequence, the outcomes of ROA conducted in this study do not generate an accurate recommendation or consultancy for TMMeB, but merely serves as an illustration for applying the assessment framework presented in Figure 5-2. In practice, the accuracy of this study should be enhanced by performing an in-depth engineering feasibility assessment for raising the causeway.

6.2.2 Step 9: Compute the Net Present Values of the Feasible Adaptation Options for TMMeB

While the *costs* of each adaptation option for TMMeB have been identified in Step 8, its *benefits* still have to be evaluated in order to compute the *NPVs of the option* in different future sea level scenarios. The potential *benefits* of raising the causeway in a particular year in any considered scenario comprise of (1) reduction in the loss of *revenue of TMMeB* and (2) mitigation of increase in the *capital expenditures of TMMeB*. Therefore, the following formula was employed for computing the annual *benefit*:

$$Annual\ benefit = \begin{cases} \left[\left(Flooding\ hours_{No\ adaptation} - Flooding\ hours_{With\ adaptation}\right) * Flooding\ cost\ per\ hour\right] \\ ,if\ Flooding\ hours_{With\ adaptation} > 0 \\ \left[\left(Flooding\ hours_{No\ adaptation} - Flooding\ hours_{With\ adaptation}\right) * Flooding\ cost\ per\ hour \right. \\ \left. +\ Raise\ in\ maintenance\ cost\right],if\ Flooding\ hours_{With\ adaptation} = 0 \end{cases}$$

The formula suggests that if the number of flooding hours in a particular year is successfully reduced to zero by an adaptation option, the annual *benefit* of the option consist of not only reduction in the loss of *revenue of TMMeB*, but also elimination of the need to increase the *capital expenditures of TMMeB*. However, if the causeway is still flooded, the annual *benefits* will only comprise of reduction in the loss of *revenue of TMMeB*. This is because additional maintenance will still be required for the causeway, which induces the raise in the *capital expenditures of TMMeB*.

Once the annual *benefits* for each option under different scenarios are known, ROA can be executed to approximate the viable and efficient adaptation option for TMMeB. A summary of ROA results is presented in Table 6-2. It indicates that raising the causeway by up to 900mm is financially viable at the present time as the *Values at Risk* of the associated climate adaptation investment options are positive, assuming a confidence level of 95%. Moreover, Table 6-2 shows the *expected NPVs* of all viable options. From their *expected NPVs,* it can be concluded that the option of raising the causeway by 200mm is currently the financially viable and efficient one as it has not only a positive *Value at Risk*, but also the highest *expected NPV* among all viable options. To further illustrate the outcomes of ROA, cumulative probability distributions of *NPVs* of raising the causeway by 100mm, 200mm and 300mm, as well as their *Values at Risk* and *expected NPVs* are presented in Figure 6-6.

Table 6-2: Summary of the financial viabilities and efficiencies of different adaptation options for TMMeB

Adaptation option for causeway	5% Value at Risk of NPV of adaptation investment (2010 USD)	Viable? (Yes/No)	Expected NPV (2010 USD)	The financially viable and efficient option
+100mm	626,474	Yes	818,727	+200mm
+200mm	621,368	Yes	905,241	
+300mm	536,199	Yes	820,072	
+400mm	451,029	Yes	734,903	
+500mm	365,860	Yes	649,733	
+600mm	280,691	Yes	564,564	
+700mm	195,522	Yes	479,395	
+800mm	110,352	Yes	394,226	
+900mm	25,183	Yes	309,056	
+1,000mm	-59,986	No	N/A	
+1,100mm	-145,155	No	N/A	
+1,200mm	-230,325	No	N/A	
+1,300mm	-315,494	No	N/A	
+1,400mm	-400,663	No	N/A	
+1,500mm	-485,832	No	N/A	

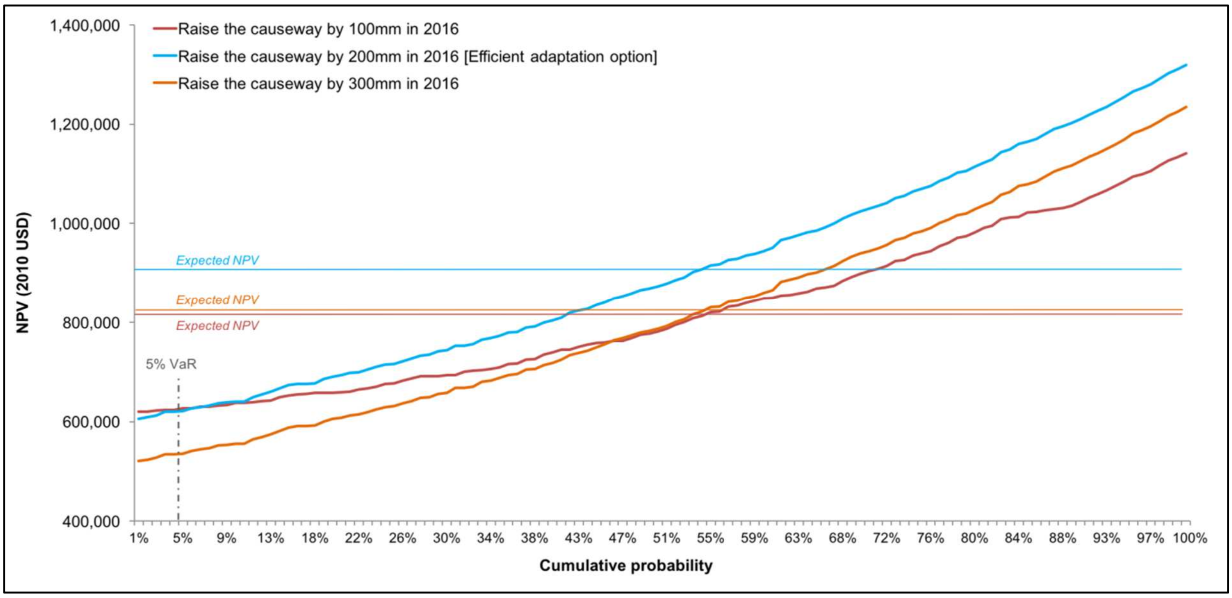

Figure 6-6: Cumulative probability distributions of Net Present Values of several adaptation options for TMMeB

6.3 Sensitivity Analysis

A series of sensitivity analyses was also conducted to analyze how the recommendation of the financially viable and efficient adaptation option for TMMeB is affected by the employed discount rate and assumptions. The study of the sensitivity to discount rate could also be utilized to explore whether the recommended option will be altered if the analysis is conducted from a social perspective or if the average cost of capital of the financer is changed. Moreover, evaluating the sensitivity of the recommendation to the assumptions allows an assessment of the robustness of the recommendation. As described in Chapter 6.1 and Chapter 6.2, five main sets of assumptions were used to simplify the case study, which are listed as follows:

- **Assumptions Set 1:** The raise in *capital expenditures of TMMeB* induced by causeway flooding was assumed to be the same as the maintenance cost of the causeway during high precipitation month, which is USD 35,000 per year. Moreover, the flooding hours in any year were considered to be interconnected, such that the increase in *capital expenditures of TMMeB* is materialized at most once in a year. To account for these simplifications, the raise in *capital expenditures of TMMeB* was varied from USD 35,000 per year to USD 140,000 per year. In this way, any potential increase in the maintenance cost of the causeway to USD 70,000 per flooding event and the probability that flooding events can occur up to 2 times in a year can be evaluated.
- **Assumptions Set 2:** The effect of empty stock flooding on the *NPV of all cash flows from TMMeB operations* was not considered in the case study. In fact, such flooding is also expected to raise the *capital expenditures of TMMeB* and subsequently increase the negative effect on the *NPV of TMMeB*. But, because of the absence of costs of adaptation options for the empty stock, the simplification was not considered in the sensitivity analysis.
- **Assumptions Set 3:** The study assumes that the variance of annual sea level distribution in TMMeB is constant throughout the assessment time frame. However, climate change could induce more intense and more frequent seasonal variations and storm events, such that the variance can be expected to rise with time. In this way, the viable and efficient adaptation level could be altered. Nevertheless, potential changes in the variance are rather unknown and therefore this uncertainty was not addressed in the sensitivity analysis.
- **Assumptions Set 4:** To simplify the calculation of the effect of causeway flooding on the *NPV of all cash flows from TMMeB operations*, two arbitrary assumptions of (1) the terminal operates for 24 hours a day and (2) the flow of containers is uniform throughout the day were employed for the assessment. Therefore, it is intriguing to evaluate the sensitivity of the assessment outcomes to the simplification. Nonetheless, as a result of the absences of extensive seawater modelling and knowledge of accurate variance in container flows in TMMeB within a day, such sensitivity analysis could not be conducted.

- **Assumptions Set 5:** The construction time for raising the causeway was simply treated as linearly proportional to the increment level in the assessment. In reality, it can be expected that the construction time increases with slower rate as the adaptation level is raised. This is mainly because causeway pavement is only required once regardless of the increment level, while the linearly proportional assumption implies that the road has to be paved whenever a volume of construction materials equivalent to the volume required to raise it by 100mm is poured. However, because of the absence of a comprehensive engineering study for raising the causeway, which was excluded from the scope of this study, sensitivity analysis of the recommended adaptation option to the construction times for different adaptation options was not performed.

This section reports the outcomes of the sensitivity analyses of the recommendation to (1) *annual discount rate* employed for the assessment and (2) increase in the annual *capital expenditures of TMMeB* because of seawater flooding.

6.3.1 Sensitivity Analysis of the Assessment Outcomes to Discount Rate

Although the appropriate *discount rate* for the assessment has been determined, it was still beneficial to examine the sensitivity of the recommendation to the *discount rate* selection. Such analysis could serve the purpose of exploring whether the recommendation will be altered if the adaptation investment is assessed from the societal perspective, in which the *real social discount rate* for Colombia (i.e. about 4%) should be employed for the analysis. Moreover, the financial structure of the terminal operator might be different in the future. According to The World Bank Group (2016a), in the past 20 years, the *annual real interest rate* in Colombia fluctuated from 4% to 24%. Therefore, the *annual discount rate* for the sensitivity assessment was varied from 4% to 24%, with an increment of 4%, to account for the *real social discount rate* and potential fluctuation in the *real private discount rate* in the future.

The outcomes of the sensitivity analysis are summarized in Figure 6-7. As expected, the *NPV* of each adaptation option exponentially declines with the *discount rate* due to the nature of the *NPV* computation. Moreover, the assessment framework recommends dissimilar sets of viable adaptation options at different *discount rates*. For instance, as shown in Figure 6-7, raising the causeway by 400mm is not viable when the *rate* of 24% is adopted. Moreover, the efficient adaptation level is altered once the *rate* is raised from 12% to 16%. This is mostly explained by the fact that the adaptation cost and the benefits accrued in the very early period of the assessment time frame play much higher weights than the benefits obtained afterwards. Therefore, at a high *discount rate*, minimizing the adaptation cost is very significant for enhancing the financial efficiency of the investment. Hence, the adaptation level of 100mm prevails as it requires the least cost among all considered adaptation levels.

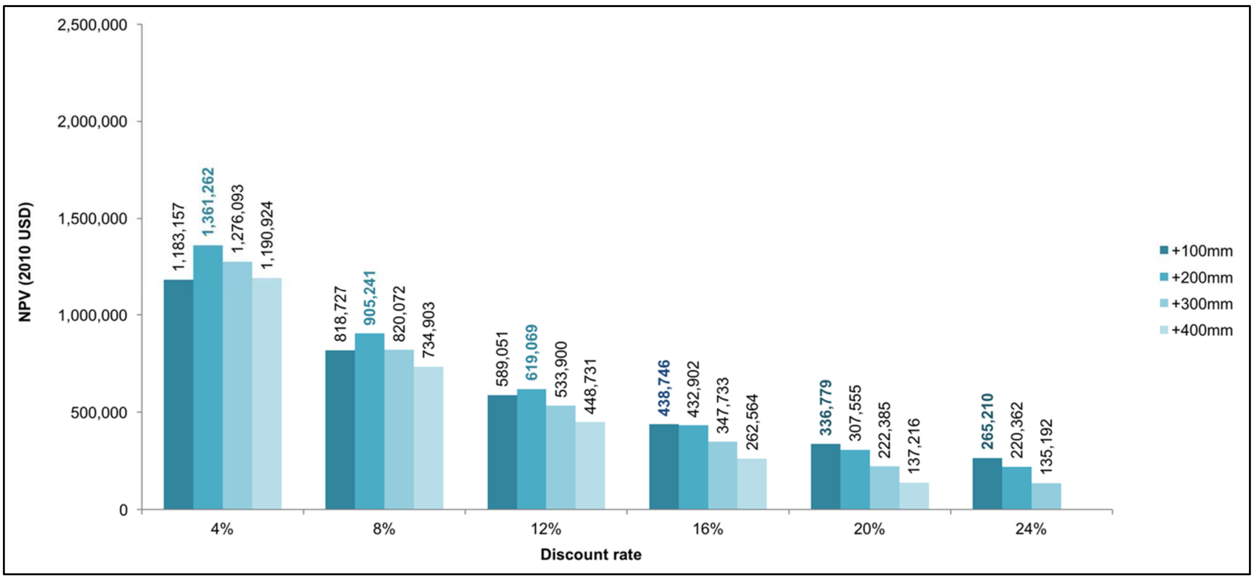

Figure 6-7: The sensitivity of Net Present Values of different adaptation options for TMMeB to discount rate

6.3.2 Sensitivity Analysis of the Assessment Outcomes to Increase in Annual Capital Expenditures

Secondly, as described in the beginning of Chapter 6.3, the annual increase in *capital expenditures of TMMeB* induced by causeway flooding were altered from USD 35,000/year to USD 140,000/year, with an increment of USD 35,000/year, in order to account for (1) the possible higher maintenance cost as a result of saltwater intrusion to the causeway and (2) the possibility that two flooding events may occur in any year. The summary outcomes of the analysis are presented in Table 6-3. It indicates that as the rise in annual *capital expenditures* is higher, the number of viable adaptation options increases. This is mainly contributed by the fact that the *benefits* offered by each adaptation option will be higher if the increase in annual *capital expenditures* induced by causeway flooding is greater. Therefore, more costly options become financially viable as the annual *expenditures* are raised from USD 35,000/year to USD 140,000/year. Moreover, Table 6-3 shows that the financially viable and efficient adaptation option for TMMeB was found insensitive to the raise in annual *capital expenditures*. The insensitivity arises as each adaptation option receives the same amount of additional *benefits* once the *expenditures* are raised.

Table 6-3: Outcomes of sensitivity analysis of the recommended option to the increase in annual capital expenditures

Increase in the annual capital expenditures as a result of causeway flooding (2010 USD)	Financially viable adaptation options	The financially viable and efficient adaptation option
USD 35,000/year	Up to +900mm	+200mm
USD 70,000/year	Up to +1,300mm	+200mm
USD 105,000/year	Up to +1,500mm	+200mm
USD 140,000/year	Up to +1,500mm	+200mm

6.3.3 Conclusion of Sensitivity Analysis

All in all, the conducted sensitivity analyses suggest that the recommended climate adaptation option for TMMeB is rather robust with respected to the considered financial parameter and assumption. Firstly, it is insensitive to the increase in *annual capital expenditures of TMMeB* induced by causeway flooding. Secondly, the recommendation is not altered when the *real social discount rate* for Colombia is employed for the assessment. Moreover, the viable and efficient option is unchanged when the *rate* is raised up to 12%. But, once the *rate* is varied to 16%, the recommended option is altered to the one that minimizes the cost of adaptation in the very beginning of the assessment time frame (i.e. +100mm adaptation level for the causeway).

The effects of other assumptions on the analysis are still unknown as they could not be incorporated into the present sensitivity analyses. Therefore, it still could not be deduced that the outcomes of the assessment are fully robust to all of the assumptions that were made for the case study. Further, although the outcome of the study appears to be the same as the recommendation advised by Stenek et al. (2011, p. 66), in which the causeway was suggested to be raised by 200mm in the beginning of the assessment time frame, it cannot be directly concluded that the developed assessment framework reaches the same conclusion as the analysis performed by Stenek et al. (2011). This is because the fictitious case study only takes containers handling, transportation and storing operations in TMMeB into account, while Stenek et al. (2011) attempted to consider all operations in TMMeB. Moreover, different assessment time frames were employed. On one hand, this study found that the appropriate time horizon for the analysis is 2032. On the other hand, Stenek et al. (2011) used an assessment time horizon of 2100.

6.4 Discussion on the Applicability and Generalizability of the Assessment Framework

Based on the conducted case study, the following data or information are found important for applying the assessment framework presented in Figure 5-2 effectively:

- Components of *cash flows from operations of the assessed port*.
- The significant climate risks for the port and their relevant weather variables.
- The potential impacts of the risks on each component of *cash flows from operations of the assessed port*.

- Historical data of the relevant weather variables with appropriate quality for research purpose and their future projections within the assessment time frame.
- Appropriate *discount rate* for the assessment.
- Effective and feasible climate adaptation options for the port and their *costs*.

Firstly, the components of *cash flows from port operations* and the appropriate *discount rate* can be identified by analyzing the business models and financial structures of the relevant port stakeholders. Secondly, the significant climate risks for the assessed port can be recognized by conducting a system-based and integrated climate risks and opportunities assessment for the port. Thirdly, an in-depth engineering study for adapting the port to climate change will allow the effective and feasible adaptation options for the port, as well as their *costs* to be identified. Fourthly, the potential impacts of the risks on *cash flows from port operations* could be estimated based on the observed impacts of the materialization of the risks in the past. Lastly, as discussed in Chapter 5.1, the historical data of the relevant weather variables could be drawn from meteorological stations situated within or nearby the port.

Although a majority of the required data has been successfully collected for the fictitious TMMeB case study, some assumptions were still required to apply the assessment framework on TMMeB. While several of them would not be needed if an extensive sea water modelling and an in-depth engineering study were conducted, several others will still be required regardless of how extensive the data collection and engineering analysis are. Firstly, the increases in the frequency and intensity of sea level extremes still could not be projected with high confidence (Church et al., 2014, p. 1200). As a consequence, it would be difficult to incorporate the effect of more frequent and more intense extreme weather events into the assessment effectively.

Secondly, the assessment for TMMeB has not considered the potential additional benefits from executing one-off adaptation strategy (i.e. raising the causeway sufficiently high in the beginning of the assessment time frame) and the possible additional costs for performing the recommended phased adaptation option (i.e. gradually raising the causeway). In fact, the additional benefits and costs could be significant and hence are not negligible. For instance, by performing a sufficient one-off adaptation in the very beginning, the reputation of the terminal could be enhanced, leading to increase in the terminal demand/call and hence higher financial profits for the operator. Such factor, which is difficult to be quantified with acceptable accuracy, would negatively affect the accuracy of the recommendation generated by the assessment framework.

Based on the two described limitations, it can be concluded that the accuracy of the assessment still cannot be justified with high confidence due to the absence of knowledge about (1) future climate variability and (2) financial values of intangible benefits and costs of different climate adaptation options. To compensate for the unavailable information, several assumptions are required for applying the proposed assessment framework on ports. Therefore, the outcomes of the assessment are subjected to the employed assumptions, and so does the accuracy of the generated recommendation.

Moreover, as TMMeB only faced one climate risk (i.e. sea level rise) and hence the case can be classified as a rather simple one, the generalizability of the framework for other ports could not be directly confirmed by this research. This is because some other ports could face a variety of climate risks, which would also occur at the same time. Therefore, additional studies are imperative to evaluate and enhance the generalizability of the developed framework.

Part IV

Financing Climate Adaptation in Ports

Chapter 7 - A Proposal for Allocating Climate Risks and Responsibilities in Landlord Container Terminals

Once the financially viable and efficient option for adapting a port to climate change has been identified, it is essential to acknowledge the responsible financers for the adaptation. Otherwise, the option, regardless of its effectiveness, financial viability and financial efficiency, would not necessarily be brought into action. As described in Chapter 1.4 and Appendix A, in a landlord port, public-private partnerships for its development and/or operations exist.

In general, the authority is the owner of land and large-scale port infrastructures and grants concessions to private operators for operating a terminal on a specific plot for an agreed time period. The operations are performed using superstructures and vehicles installed and owned by the operators. In this way, climate risks have implications to both the authority and operators. On one hand, they could damage terminal infrastructures owned by the port authority, which reduces not only the financial value of assets owned by the authority, but also the functionality of the terminal and hence its attractiveness to private operators and clients. Therefore, the impacts could later lead to reduction in the revenues of the authority from concession fees and port dues. On the other hand, the risks could also halt the operations of terminal operators and even damage their assets, which induce reduction in their revenues and financial values of their assets.

Although the responsible financer for climate adaptation in TMMeB has been clearly expressed, Sundararajan and Suriyagoda (2016) claim that climate risks have not been explicitly considered and allocated to specific parties in most other cases. Therefore, the port stakeholder responsible for financing each adaptation measure in a landlord port might not be readily apparent. In this regard, there is a need to explicitly allocate climate risks and responsibilities to achieve investments in their climate resiliencies.

This chapter aims to discuss the potential of allocating climate risks and responsibilities in landlord container terminals explicitly and effectively among port stakeholders. At first, the most common partnerships and risk allocation in landlord container terminals are described. Then, the current practices to deal with climate risks in the partnerships and their effectiveness are discussed. Subsequently, the barriers to incorporate climate risks into the partnerships effectively are presented. Afterwards, based on the current practices and the identified barriers, guidelines for climate risks and responsibilities allocation in landlord container terminals are developed. The potential of the guidelines is then confirmed by examining the success factors for climate risks and responsibilities allocation in the construction and operations of Maasvlakte II, the large port extension of the Port of Rotterdam in the Netherlands.

7.1 Common Partnerships in Landlord Container Terminals

The public-private partnerships in an existing container terminal usually take the form of long-term lease (Notteboom, 2007). In such contract, the port authority is responsible for providing and maintaining terminal waterways and other main infrastructures, while terminal operators invest in quay-side facilities and other equipment. In return to the granted concession, they are required to pay concession fees to the authority regularly. In the end of the concession, the superstructures can be held by the authority with or without payment, depending on the stipulated agreements. In this case, the partnerships model can also be classified as an Equip-Operate-Transfer (EOT) one as the operators are required to (1) equip the existing terminal with their superstructures and vehicles, (2) operate and maintain them, as well as (3) transfer them to the authority in the end of the concession. Port of Tanjung Priok in Indonesia is one of the existing container terminals that employ EOT partnership to enhance its operations.

Text Box 7-1: Port of Tanjung Priok, Indonesia

The port is handling more than 50% of annual Indonesian transhipment cargos. Its operation is infamously known as one of the least efficient in South East Asia, with an average turnaround time of 6 times of that in the Port of Singapore (Artakusuma, 2012; Rizkikurniadi & Murdjito, 2013). The port is a property of the Indonesian government and currently being operated by two firms, which are the Indonesia Port Corporation and Hutchinson Port Holdings. The private holdings entered the port through an EOT agreement with the state-owned firm and it installed new equipment and provided training to improve the crane efficiency from 18-19 moves per crane per hour in April 1999 to 24-25 moves per crane per hour in late 2000 (Ray & Blankfeld, 2002).

In new terminal development, more options are feasible to allocate the responsibilities for (1) designing and (2) constructing the new terminal, (3) financing the construction and (4) operating the developed terminal (Notteboom, 2007). In general, the authority grants the new development areas to private sector, which is responsible to design and construct the relevant port infrastructures, finance the construction and equip them with essential superstructures and vehicles in support for the terminal operations.

As discussed in Aerts et al. (2014) and Notteboom (2007), one of the frequently applied partnership options in the development and operations of new landlord container terminals is Build-Operate-Transfer (BOT). In this partnership type, the port authority grants a concession to a private firm or consortium to construct a new terminal, finance the construction, maintain and operate the terminal, as well as obtain revenue from the operations afterwards within an agreed time period (Notteboom, 2007; The World Bank, 2007). Under a BOT contract, the private sector can also be required to participate in designing the terminal prior to the construction, which resembles the common construction practice in the Port of Hong Kong (van Ham & Koppenjan, 2002). In the end of the partnership, all or a majority of the developed assets are transferred to the authority. Build-Operate-Share-Transfer (BOST) is a variant of BOT, which is also employed in several new terminal developments and operations. It is similar to the BOT one, but the revenue obtained by the private entity has to be shared with the authority. Nhava Sheva International Container Terminal and Krishnapatnam Port are examples of terminals that are operated under BOT and BOST partnerships, respectively.

Text Box 7-2: Nhava Sheva International Container Terminal, India

The terminal is the first private container terminal and one of the most modern terminals in India. Its development was executed by P&O Ports (now: DP World Limited) in 1997 under a 30-year BOT agreement with the Government of India at a cost of USD 200 million (DP World Limited, 2013). The private firm completed the construction before the schedule and commenced its operations in 1999 (India. Ministry of Finance, 2010). The private participation in terminal operations results in an impressive gain in its operational efficiency. For instance, the average turnaround time in 2003-2004 was 1.84 days, which was far superior than those in comparable container terminals operated by public sector (UNESCAP, 2008).

Text Box 7-3: Krishnapatnam Port, India

Andhra Pradesh region was one of the first port cities in India that recognize (1) the need for enhanced port equipment and (2) the benefits that could be brought by private sector. The privatization of Krishnapatnam Port was conducted through a BOST agreement. The BOST contract between the Government of Andhra Pradesh and Krishnapatnam Port Company Limited stipulates that (1) the private company is granted for a concession of 30-year that can be extended by two more spells of ten-year each, (2) the revenue earned from port operations has to be shared with the government at a progressive rate, in which it was set to be 5% in the first five years and 12% in later years and (3) immovable assets are transferred to the government at no cost at the end of the concession (The Government of Andhra Pradesh, n.d.).

7.2 Risk Allocation in Container Terminal Partnerships

Apart from the development type, decisions and clauses in landlord container terminal partnerships are also based on the principle of risk allocation, in which each specific risk is allocated to the party that is best able to manage it (Sundararajan & Suriyagoda, 2016). For instance, as depicted in Figure 7-1, which illustrates the roles of private sector in various stages of container terminal development and operations under different partnership options, the risks associated with (1) installation of terminal superstructures, (2) financing the installation and (3) operation and maintenance of the installed superstructures are transferred to the private operators under EOT partnership. This is mainly because they have been operating various container terminals all over the world. Therefore, compared to port authorities, they have higher knowledge of how the superstructures should be installed, operated and maintained in an efficient manner.

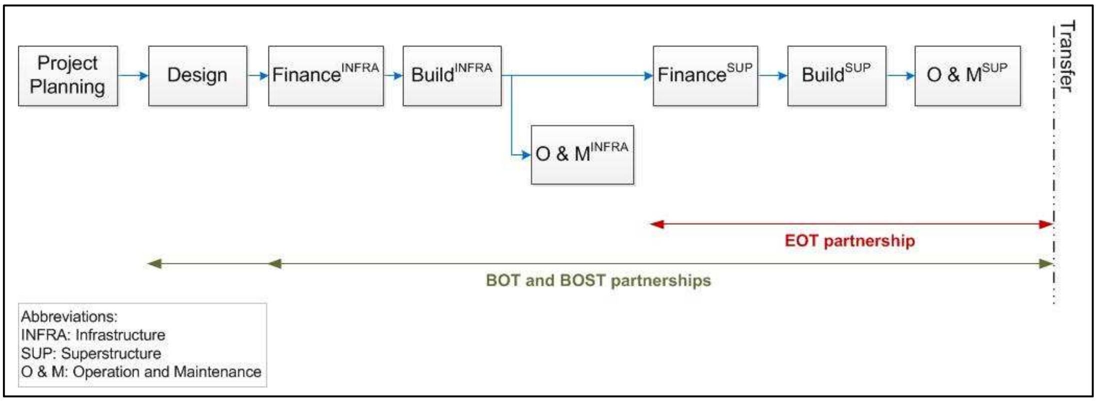

Figure 7-1: Roles of private sector in several container terminal partnerships. Source: Author

Furthermore, in common new terminal partnerships, the responsibilities of private sector are extended to include the risks of (1) designing terminal infrastructures in some cases, (2) constructing the infrastructures, (3) financing the construction, as well as (4) operating and maintaining them. Such risk transfer is executed whenever the private sector is more capable of dealing with the tasks than the port authority.

7.3 Current Practices of Dealing with Climate Risks in Container Terminal Partnerships

As investments, operations and maintenances of either (1) terminal superstructures or (2) both terminal infrastructures and superstructures are performed by private sector in landlord container terminals, their climate resiliencies are very dependent on decisions made by the private sector. However, as described in the beginning of this chapter, despite having higher likelihoods and consequences, climate risks have not been explicitly incorporated into a typical public-private partnership risk allocation framework (Sundararajan & Suriyagoda, 2016). Nevertheless, several clauses in public-private partnership contracts have implicitly considered the occurrence of adverse weather events. In a port partnership, private sector mostly requires the port authority to provide contractual protections for its investments. Such protections are agreed in the risk allocation processes and act as the guidance for actions in case of occurrence of adverse weather events. As elaborated in Sundararajan and Suriyagoda (2016), six protections against climate risks are generally included in public-private partnerships. Each of them is described in this section concisely.

7.3.1 Relief and Compensation Events

Both relief and compensation events require the private sector to restore assets affected by the pre-identified adverse weather events. If an adverse weather event is regarded as a relief event in the contract, the private sector is exempted from the failure to meet its obligations for maintaining the operability of the assets during the event. However, no financial compensation is given by the port authority to (1) aid the private sector in reinstating the assets and (2) recover any financial loss suffered as a result of the operational interruption (The World Bank Group, 2016b). In contrast, if an adverse weather event occurs and it is considered as a compensation event, the authority will not only relieve the private sector from its responsibilities, but also provide financial compensations to cover (1) the replenishment costs of the damaged assets and (2) the revenue lost experienced by the private entity.

7.3.2 Force Majeure Events

The occurrence of extremely adverse weather events is mostly considered as a force majeure event in port partnerships. Force majeure encompasses all events that are unforeseeable, unavoidable and external that makes mitigation to their impacts implausible (The World Bank Group, 2015). In case of materialization of any force majeure event, both the port authority and private sector are allowed to terminate their partnership, especially if the impact of the event has lasted for a prolonged time period (e.g. 180 days). In such termination, both parties share the financial burdens, in which the authority generally pays the debt and equity obligations of the private sector instead of recovering the damaged assets. According to Sundararajan and Suriyagoda (2016), temporary and short-term force majeure events could also be treated as relief or compensation events if they have been pre-agreed in the contract.

7.3.3 Insurance

In a typical port partnership, both port authority and private sector can agree to transfer several risks, including climate risks, to third-party insurers. However, the transfer is not as easy as turning one’s hand over as the insurers are very likely to insist them to perform disciplined climate risk management practices. Otherwise, the insurance premium will be significantly raised and/or any loss induced by the occurrence of adverse weather events will not be fully covered.

7.3.4 Uninsurable Events

Uninsurable events arise from the fact that some risks, inclusive of risks induced by adverse weather events, are not insurable as no insurer is willing to cover the risks or the premium for transferring the risks is very expensive. In most cases of uninsurable events, the public sector (i.e. public port authority or government) is responsible for the impacts of such events by default and hence acting as the insurer of the last resort. In rare cases, private sector is obliged to bear the risks of those uninsurable events, mostly at higher return promises (Sundararajan & Suriyagoda, 2016).

7.3.5 Change in Law

As many countries have started to pledge in reducing their greenhouse gas emissions, their environmental laws continue to be strengthened. Therefore, changes in design and construction codes, as well as regulatory limits on the emissions are very expected, which could lead to higher construction and operational expenditures. The protection against change in law is generally included in public-private partnerships, such that the private sector is protected from the consequences of such alteration in regulations. If any relevant regulation is changed, the public sector has to cover the additional construction and operational expenses resulting from the more stringent regulations (Sundararajan & Suriyagoda, 2016).

7.3.6 Variations and Renegotiations

In some agreements, variation and renegotiation mechanisms are embedded to manage unforeseen events that later occur during the partnership period. As elaborated in Sundararajan and Suriyagoda (2016), the variation mechanism is usually based on the pre-agreed cost structures or types of changes allowed to the pre-defined obligations. For instance, private operators may get exempted from concession fee payment for a certain time period if long-term impacts of any adverse weather event are experienced. Similarly, renegotiations on the pre-agreed obligations are allowed in some partnerships, although extreme cautions for implementing them are required to ensure that the altered contracts are fair and still beneficial for both parties.

7.4 Effectiveness of the Existing Contractual Protections

At first glance, the existing contractual protections against climate risks in public-private partnerships may appear to be comprehensive and incorporate climate risks well. However, several limitations of the protections were found. First of all, it is hardly possible to list all climate risks that are significant to partnerships in landlord container terminals as the risks that are currently irrelevant could be significant in the future due to climate change. Secondly, it is unclear whether a particular climate risk is best considered as a relief, compensation or force majeure event as a result of its growing likelihood and potential impacts (Sundararajan & Suriyagoda, 2016). As a consequence, climate risks and responsibilities could not be allocated among port stakeholders effectively only by using the currently implemented contractual protections. Thirdly, because of the rising climate risks, the number of insurance companies willing to protect terminal assets and operations against the risks is expected to decline. Even if they are still interested, they are very likely to raise the insurance premium, which reduces the attractiveness of container terminal partnerships for private sector. Moreover, insurance against climate risks is not available in some regions, in particular in developing countries and regions highly exposed to the risks.

Last but not least, the protections only address climate risks as ex-post events (i.e. reacting to the materialized risks) instead of ex-ante ones (i.e. proactively manage the risks and build resilience against them) (Sundararajan & Suriyagoda, 2016). Therefore, climate resiliencies of landlord container terminals have not been addressed by them. In this case, the terminals are very likely to be negatively affected once any adverse weather event occurs, leading to lower lifetimes of terminal assets than the expected ones. Such catastrophic impacts would also reduce the reputations of the terminals and could negatively impact regional and national economies, which are not insurable and not instantly recoverable.

7.5 Barriers to Effectively Incorporate Climate Risks into Container Terminal Partnerships

Although it is beneficial to explicitly state the allocation of climate risks by distributing responsibilities to enhance climate resiliencies of terminal assets and operations into the partnerships, there are multiple barriers that hinder such incorporations. Sundararajan and Suriyagoda (2016) have identified the key hurdles and they are discussed in this section.

7.5.1 Reduction in the Attractiveness of Container Terminal Partnerships

The incorporation of (1) climate risks and (2) requirements for climate resiliencies of terminal assets and operations into the responsibilities of private sector may reduce the attractiveness of partnerships in landlord container terminals for both the port authority and the private sector. On one hand, private sector will demand higher compensation to the authority for dealing with the risks and delivering climate resilient assets and operations. In this way, the expenditures of the authority could be raised if it has to finance the construction, while its revenue from concession fees might be reduced if the private operators ask for discounts. On the other hand, the transfer of climate risks to private sector is expected to enlarge its project risks. As future climate risks are uncertain and so do the required efforts to meet the climate resilience requirements, private sector would be less attracted to the offered partnerships.

7.5.2 Procurement Bias towards the Lowest Bidder

Currently, the competitive bidding process is highly biased towards financial evaluation criteria, in which the bidder that can provide the required services with the lowest offered price is selected as the winner. In this case, bidders that pledge to deliver climate resilient terminal assets and/or operations could be overlooked because the offered price generally increases with the resilience level. Moreover, knowing that the selection criteria is heavily biased towards the offered price, bidders would be demotivated to consider climate resilient assets and operations in their proposals as this will lessen their chances to win the tender.

7.5.3 Mismatch between the Partnership Period and the Expected Lifetimes of the Delivered Assets

The costing approach in container terminal partnerships is mostly limited to the partnership period instead of the expected lifetimes of the delivered assets. Therefore, the payment made by the authority is mainly based on the performance of the assets during the contractual period. However, in general, the delivered port assets are long-lived, while the partnership period is shorter. In this case, private sector has a tendency to only consider climate risks that could materialize during the concession period, but not the risks that might occur afterwards. Hence, the lifetimes of terminal assets delivered through container terminal partnerships could be shorter than the expected lifetimes in view of rising climate change impacts.

7.5.4 Principal-agent Problem

The classical principal-agent problem could also arise in landlord container terminal partnerships as (1) the port authority and the private sector may have different interests and (2) information asymmetry exists between them. Information asymmetry presents when one party possesses more knowledge on a particular matter and therefore can use it to take advantage from others. For instance, a private contractor that wins a tender for constructing container terminal infrastructures has a higher understanding about the actual climate resiliencies of the delivered infrastructures as compared to the port authority. This is because the actions of the contractor are not completely observable by the authority and hence the authority is less knowledgeable about the outcomes of the construction (Altamirano, 2010). In this case, the contractor can execute immoral actions to gain benefits from the authority. An example of such actions is the ability of the private contractor to construct terminal infrastructures that only meet the specified climate resilience requirements during the partnership period, but not for their entire expected lifetimes.

7.5.5 Rigid Contracts in Container Terminal Partnerships

In principle, the rigid or deterministic character of contracts in landlord container terminal partnerships is not effective for managing the uncertain and dynamic climate risks. For example, as previously described in Chapter 7.4, rare and adverse weather events that are not significant in the past could get intensified during the partnerships, such that they are no longer appropriate to be considered as force majeure events. Therefore, adaptive approach in the partnerships is needed for dealing with climate risks effectively.

7.6 Guidelines for Climate Risks and Responsibilities Allocation in Landlord Container Terminals

All in all, improvements in the current practices of landlord container terminal partnerships are required for incorporating climate risks and resiliencies into the partnerships effectively. Based on the existing contractual protections against climate risks and the barriers for an effective incorporation of the risks into the partnerships discussed in Chapter 7.3 and Chapter 7.5, respectively, several possible measures to enhance climate risk management in landlord container terminals were identified in this research. They are listed as follows:

- The party that bears the responsibility for reinstating terminal assets and operations following each of the unmitigable and unmitigated adverse weather events, including the pre-identified, rare, unexpected and unknown ones, should be explicitly stated in the contract. Alternatively, the contractual protection applicable to each of them can be specified in the contractual agreements.
- Variation and renegotiation clauses could be embedded into terminal partnerships to deal with climate risks that are rising in terms of their likelihoods and consequences. Whenever possible, the appropriate thresholds of likelihood and/or consequences for each of the unmitigable and unmitigated climate risks could be stated in the contract. In this way, once the threshold is reached, the contractual protection applicable to the risk could be varied or re-negotiated. As an example, any rare and adverse weather event that occurs at most once every 20 years when the contract is signed could be firstly regarded as a force majeure event. However, once such event gets intensified and is experienced more frequent than the threshold during the partnership period, the event could be considered as either relief or compensation event through variation or renegotiation clause.
- The private sector should be informed about which existing terminal assets have been and will be insured to external insurers by the port authority. Moreover, agreement on which party is responsible for insuring the constructed terminal assets during the partnership period, if needed, should be indicated in the contract.
- For all uninsured and uninsurable events, the party responsible for recovering the resulting financial losses has to be clearly stated in the contract. If an external party (e.g. government) is expected to compensate for the losses, it is very beneficial if the party is consulted prior to the partnership agreements.

- The port authority has to consider the trade-off between the offered service prices and the pledged climate resiliencies of the terminal assets and/or operations in the tendering process. Or, the climate resilience requirements could be clearly specified in the tender documents and contracts. From the author's point of view, examples of the requirements could be (1) the developed infrastructures should not be flooded from any event that induces sea level of up to 5 meters and (2) the delivered quay cranes shall be capable of loading and unloading at least 25 containers/hour/crane whenever the wind speed is less than 20 m/s.
- To incentivize the private sector in providing terminal assets that are climate resilient during not only the partnership period but also their expected lifetimes, two possible solutions could be implemented. Firstly, the entire partnership period could be simply extended to the expected lifetimes of the assets. Secondly, if the period has to be made shorter than the expected lifetimes, the port authority can still execute an option of transferring the obligation of maintaining the delivered port assets until the end of their expected lifecycles to the private sector. In both cases, the private sector is expected to be more willing to deliver climate resilient assets as its revenue will be reduced once the assets fail to cope with any pre-specified adverse weather event.

The listed measures could be expected to assist in (1) enhancing the effectiveness of the existing contractual protections against climate risks in landlord container terminal partnerships, (2) translating the rigid protections into the adaptive ones to ensure their effectiveness by taking into account the uncertain climate change, (3) mitigating the negative effects of procurement bias on climate resiliencies of the delivered terminal assets and/or operations and (4) minimizing the mismatch between the partnership period and the expected lifetimes of the delivered assets.

An exploration of the success factors of the Port of Rotterdam Authority for allocating climate risks and responsibilities between the authority and private sector in the development and operations of Maasvlakte II reveals that all of the proposed measures, except for the second one, have been partially adopted into the partnerships (see Text Box 7-4). Therefore, their applicability into port partnerships could be considered promising. However, to the knowledge of the author, the second suggested strategy, which are aimed to raise the effectiveness of existing contractual protections against all unmitigable and unmitigated climate risks, have not been implemented in Maasvlakte II. In this regard, its feasibility still has to be explored. Nevertheless, the recommended action is in line with the proposal for implementing adaptive relational contracts for transportation infrastructures by Altamirano et al. (2015) (see Text Box 7-5). Hence, it has at least contributed to discussion about the benefits offered by adaptive contracts in public-private partnerships.

Text Box 7-4: Successful Case of Climate Risks and Responsibilities Allocation in Maasvlakte II

To meet the increasing demand for the Port of Rotterdam in the future, as well as to maintain its leading role in port industry, the Port of Rotterdam Authority decided to expand the port to the west (The Port of Rotterdam Authority, n.d.b). The expansion project is referred to as Maasvlakte II project, in accordance with the name of the new port region. In this research, a case study of successful climate risks and responsibilities allocation in Maasvlakte II was performed to evaluate the applicability of the proposed measures in container terminal partnerships in practice. Information on the partnerships for reclaiming and operating Maasvlakte II was collected from existing literature, a formal interview with Prof. Tiedo Vellinga, who was the Director of Environmental Monitoring for Maasvlakte II and an informal conversation with an employee of the Port of Rotterdam Authority, whose personal details cannot be presented in this thesis for confidentiality reasons.

From the collected information, it was learned that the authority formed two different partnerships for the construction and operations of Maasvlakte II, instead of assigning the tasks to the private sector through one partnership, as in the BOT option. Firstly, the authority is in a Design-Build-Maintain (DBM) contract with PUMA, a private port contractor that is responsible to design and construct the infrastructures of Maasvlakte II and maintain them for a period of 25-year thereafter (Boskalis, n.d.; van den Dool, 2012). On one hand, the task of infrastructure design was also transferred to the private sector to ensure that the design matches with the engineering capability of the contractor (van den Dool, 2012). On the other hand, the project financing risk is solely borne by the authority, such that it has to handle a large portion of financial risks in the project. Nevertheless, the authority is interested in financing the reclamation in order to maintain their controls over (1) enforcing the standards of the developed port infrastructures and (2) making rules and regulations applicable within the newly developed port area (van den Dool, 2012).

Secondly, the operations of the developed Maasvlakte II container terminals are leased to private operators. The operation of the first terminal was awarded to a private consortium of DP World, APL, MOL, HMM and CMA-CGM following a competitive bidding process, while the operation of the second terminal was granted to APM Terminals following a direct negotiation between the authority and the private firm (Pallis et al., 2008; Vellinga, 2016a). However, as the concession for the second terminal was subjected to several political issues, only concession for the first terminal is presented in this thesis.

Contractual Agreements for Construction of Maasvlakte II Infrastructures

A competitive tendering was used to select the most appropriate contractor for reclaiming Maasvlakte II. The criteria employed to determine the winning bidder were based on a mixture of (1) construction costs, (2) time to complete the construction, (3) maintenance costs and (4) contractual risks associated to each applicant (van den Dool, 2012). Although the process of meeting the required output specifications was left to the winning bidder (i.e. PUMA), all roles and tasks of both the authority and the contractor had been identified clearly before the project began (van den Dool, 2012). Moreover, in the context of port development in the Netherlands, many potential risks, including delay, relief, compensation and force majeure events are identified prior to the contract signing (van den Dool, 2012). Consequently, they have been stated in the contract and therefore incorporated explicitly.

Apart from specifications that are generally found in the contractual agreement of new port development, the climate resilience requirements of infrastructures in Maasvlakte II have also been clearly stipulated in the tendering documents and contracts. As an example, PUMA is required to perform sand-filling to the coastline of Maasvlakte II to a certain level for preventing the new port region from seawater flooding (Vellinga, 2016a). However, if climate change evolves faster than the expected, the adaptation level will have to be enhanced. In this case, the authority could require PUMA to execute additional sand-filling to enhance the resilience level of the developed infrastructures. In this case, the authority will be required to fund the additional cost (Vellinga, 2016a). The incorporation of the climate resilience requirements was done to support the goal of the City of Rotterdam to be a climate-proof city by 2025 (Vellinga, 2016a; Vellinga, 2016b).

However, none of the currently developed port infrastructures is insured to a third-party insurer as the premium for insuring those assets is very high (Vellinga, 2016a). In fact, in the Netherlands, it is hardly possible to insure assets against climate risks with reasonable prices, in particular those exposed to the risk of seawater flooding, because of the unique topography of some regions of the country, which is lower than the sea level in most of the time (de Jong, personal communication, 13th May 2016; Vellinga, 2016b). Nevertheless, the Dutch government considers the Port of Rotterdam as an important national asset and therefore the port will be replenished whenever an extreme weather event occurs and negatively affects its infrastructures and operations (Vellinga, 2016a).

Concession of the First Container Terminal in Maasvlakte II

The tendering for the operations of the first container terminal in Maasvlakte II comprised of two processes. Firstly, the authority implemented a pre-qualification process, in which only private terminal operators that had handled at least 2 million container units in the previous year could participate in the tendering (van den Dool, 2012). This was done to ensure that only key players in the container shipping industry were considered in the process (van den Dool, 2012). The large size of the terminal and the high reputation of the port attracted private operators, which contributed to the formation of 6 consortia that expressed interests in operating the terminal (Pallis et al., 2008). Following that, an expression of interest document was signed by each interested party (van den Dool, 2012).

Secondly, the Port of Rotterdam Authority disclosed more information about the details of the container terminal and its criteria for selecting the winning bidder. In this process, the authority was very transparent about (1) climate risks faced by the terminal and (2) climate adaptation measures that have been and will be performed by the authority (Vellinga, 2016a). The potential impacts of any adverse weather event on the terminal that have not been mitigated by the adaptation measures are borne by the winning bidder (Vellinga, 2016a). Moreover, the winning bidder is required to maintain and protect its leaseholds and superstructures from any damage, including damage induced by adverse weather events, such as seawater flooding (Tieman, 2014 as cited by Smith, 2015; Vellinga, 2016a). Therefore, the responsibilities to mitigate the terminal from any impact of adverse weather events that are not borne by the authority belong to the winning bidder (Vellinga, 2016a). Any additional climate adaptation measure in the terminal operational area should be executed and financed by the winning bidder, with the approval from the authority beforehand (Vellinga, 2016a).

The authority employed a multi-criteria selection method to determine the winning bidder. The criteria include (1) financial bid (40% weighting factor), (2) the competitiveness of the offered business plan (25%), (3) sustainability performance of the presented plan (20%) and (4) terminal concept and technology proposed (15%) (Pallis et al. 2008; van den Dool, 2012). It is intriguing to note that it was the first time in the world that a port authority includes such sustainability indicator in the selection criteria (The Port of Rotterdam Authority, n.d.a). The inclusion was aimed to support the ambition of the Port of Rotterdam Authority to be the landlord of the world's most sustainable port (The Port of Rotterdam Authority, n.d.c).

Under the sustainability criterion, the interested private consortia had to explicitly express their proposed (1) environmental management system, (2) modal-shift measures, (3) security of terminals and the transport chains (The Port of Rotterdam Authority, n.d.a). The environmental management system proposal encompasses the promised efforts of each bidder with regard to air pollutants generated, energy consumed and waste produced by the terminal operations (The Port of Rotterdam Authority, n.d.a). Moreover, the modal-shift proposal required each bidder to elaborate the proposed proportion of road, inland waterway and rail hinterland transportation modes for the served containers (The Port of Rotterdam Authority, n.d.a). This was included to support the goal of the authority to reduce its dependency on trucks for hinterland transportation, which is currently the main contributor to the port's emissions (The Port of Rotterdam Authority, n.d.a). Meanwhile, the security of terminal and transport chains refers to the sustainability of terminal operations. However, it did not explicitly require the inclusion of operational procedures that will be undertaken by the bidders during adverse weather events (Vellinga, 2016b).

In the end, a consortium of DP World, APL, MOL, HMM and CMA-CGM won the tender and has started the operation of the first container terminal, which is named as the Rotterdam World Gateway terminal, since September 2015 (DP World Limited, 2016). The private sector is granted for operating the terminal for a period of 25-year and required to pay concession fee regularly to the Port of Rotterdam Authority (Vellinga, 2016b). Similar to the concession practice in other container terminals in the Port of Rotterdam, the consortium is responsible for providing, installing, operating and maintaining the superstructures and equipment in support for its operations.

Success Factors for Effective Allocation of Climate Risks and Responsibilities in Maasvlakte II

From the elaborated partnerships for constructing Maasvlakte II and operating one of the container terminals, it can be concluded the Port of Rotterdam Authority has leaped over some of the barriers to effectively incorporate climate risks and responsibilities into the partnerships. First of all, the authority decided to solely finance the design, construction and maintenance works to compensate the additional risk of climate resilient requirements borne by PUMA. If the financial burden was also shifted to the contractor through a BOT partnership, private sector would be less attracted to the offered partnership. Secondly, the authority has mitigated the procurement bias towards costs by (1) explicitly stating its climate resilience requirements for the developed infrastructures in the tendering for reclaiming Maasvlakte II and (2) incorporate sustainability assessment criterion in the tendering for operating the first container terminal. In this way, although the financial criteria still played important roles in the selection of the winning bidders, the climate resiliencies of the delivered infrastructures and the sustainability of the operations are ensured. Thirdly, the rigid nature of port partnerships has been transformed into an adaptive one as the authority has an option to require the contractor to enhance the climate resiliencies of the developed infrastructures, if needed.

Text Box 7-5: Relevancy to the Proposal of Adaptive Relational Contracts by Altamirano et al. (2015)

Altamirano et al. (2015) claim that adaptive relational contracts are more advisable than complete contracts for a long-term contracting purpose because the former often results in lower flexibility for public clients (i.e. principals) and limited possibilities for changes in contract specifications or standards. To solve the issues, Altamirano et al. (2015) propose dynamic adaptive standards for a long-term partnership, in particular in road networks. The proposal is grounded on the building blocks of adaptive policies suggested by Walker et al. (2001).

First of all, the concepts of *signposts* and *triggers* of Walker et al. (2001) are employed. The former is used to identify information that should be tracked in order to determine whether any change in contract specifications or standards is needed, while the latter is employed to determine the critical values of the *signposts* variables that lead to the need for the change. Secondly, once any *trigger* is experienced, additional actions are required to ensure the effectiveness of the contract. According to Walker et al. (2001, p. 285), the actions can be classified into:

- *Mitigating actions*: actions taken in advance to reduce the certain adverse effects of a policy.
- *Hedging actions*: actions taken in advance to spread or reduce the risk of possible adverse effects of a policy.
- *Defensive actions*: actions taken to clarify the policy, preserve its benefits, or meet outside challenges.
- *Corrective actions*: adjustments to the basic policy in response to specific triggers.
- *Reassessment*: a process to be initiated or restarted when the analysis and assumptions critical to the policy's success have clearly lost validity.

The second measure of incorporating variation and renegotiation clauses into landlord container terminal partnerships for addressing unmitigable and unmitigated climate risks proposed in this research fits into the adaptive relational contracts suggested by Altamirano et al. (2015). The likelihood and/or consequences of occurrence of each of the unmitigable and unmitigated climate risks can be thought of as *signposts*, while their thresholds resemble the *triggers* concept. Moreover, the recommended variation and renegotiation clauses are analogous to the *corrective actions* and *reassessment*, respectively.

Therefore, in this research, the proposal of adaptive relational contracts for road networks by Altamirano et al. (2015) has been generalized to the port sector. Moreover, in the context of climate risk management in public-private partnerships, this research finds that the currently rigid contractual protections against climate risks could be transformed into adaptive ones using variation and renegotiation clauses. As both variation and renegotiation clauses are already present in the partnerships, their employments are likely to allow the proposed adaptive relational contracts to be more easily implemented when dealing with climate risks.

Based on the measures proposed in this research, it can be deduced that the effectiveness of climate risk management in landlord container terminals could be enhanced if the parties responsible for (1) the significant climate risks and (2) executing the effective climate adaptation measures towards them are explicitly stated in the partnership agreements. In this way, the responsible financer for each measure could be recognized effectively. To assist the port stakeholders in allocating the risks and responsibilities effectively, a matrix of climate risks and responsibilities allocation in landlord container terminals was developed based on the details that should be incorporated into the partnerships. As shown in Table 7-1, in which a matrix filled for an illustration purpose is presented, it requires the users to classify climate risks into (1) the risks that are unmitigable or are left unmitigated and (2) those would be mitigated during the partnerships. They are clearly separated in the matrix as they require different treatments.

Firstly, for all unmitigable and unmitigated risks, they should be explicitly categorized into relief, compensation, force majeure, insured and uninsurable events, which are the existing contractual protections against climate risks in public-private partnerships. In this way, the responsibilities of each party in case of materialization of each of the risks are clearly specified. Moreover, the insurance requirement against each event and the party responsible for paying the premium should be stipulated in the agreement. Further, to allow the adaptiveness of the contract for dealing with uncertain climate change effectively, the appropriate thresholds of likelihood and/or consequences for each risk can be specified in the agreement. In this way, once the threshold is exceeded, the type of contractual protection applicable to the risk can be altered by discussion through renegotiation clause or amended directly through variation clause. For instance, in the allocation of climate risks and responsibilities in a hypothetical terminal presented in Table 7-1, high winds are considered as unmitigable risks and any event that induces wind speed higher than 60 m/s is currently being treated as an insured event and the authority is responsible for financing the insurance. However, if such event is experienced as frequent as once in every 10-year in the future, it will be directly considered as a compensation event through variation clause.

Table 7-1: An example of a filled out climate risks and responsibilities allocation matrix for landlord container terminals

Climate Risks and Responsibilities Allocation Matrix for Landlord Container Terminals							
Name of Terminal		**Terminal A, Port B**					
Concession Period		**2016-2045**					
Unmitigated/Unmitigable climate risks	**Climate risk register**	**Contractual protection applied**	**Insurance requirement**		**Threshold for variation/renegotiation**		
			Yes/No	**Responsible party**	**Threshold**	**Variation/Renegotiation**	**New contractual protection under variation**
	High winds (wind speed: 20 - 45 m/s)	Relief event	Yes	Port operator	N/A	N/A	N/A
	High winds (wind speed: 45 - 60 m/s)	Compensation event	Yes	Port operator	N/A	N/A	N/A
	High winds (wind speed: > 60 m/s)	Insured event	Yes	Port authority	10-year event	Variation	Compensation event
	Seawater flooding due to hurricane	Force majeure event	No	N/A	30-year event	Variation	Compensation event
	Earthquake	Uninsurable event	N/A	N/A	50-year event	Renegotiation	N/A
Mitigated/Mitigable climate risks	**Climate risk register**	**Resilience requirement**	**Responsible party**		**Penalty for failure/non-compliance**		
	Seawater flooding due to average sea level rise and storm event	No-flooding at sea level up to 5m	Port contractor		No payment for the maintenance service for 6 months following the flooding event		
		No-flooding at sea level of 5m - 8m	Port authority		Such flooding is treated as a compensation event and port operators are exempted from concession fee for 3 months following the flooding event		
	Moderate winds (wind speed: < 20 m/s)	Goods loading and unloading speed of 25 containers/hour/crane	Port operator		The operator has to recover the loss of income of port authority from port dues as a result of inefficient port operation		

Secondly, for climate risks that would be mitigated during the partnership period, the required climate resilience levels for each port infrastructure and operation against them have to be addressed in the partnership contract. The required levels can be either directly specified by the port authority in the tendering process or included by the winning bidder in its proposal. Moreover, the party responsible for delivering each requirement should be specified in the agreement. In this way, the responsibility of each party for building climate resilient container terminals would be obvious and hence the desired resilience levels of the terminals could be more effectively achieved. Further, a penalty can be imposed on each party for failing to meet their obligations. In this case, the amount of penalty should also be explicitly stated in the agreement. As an example, Table 7-1 indicates that moderate winds are not expected to disrupt operations of the hypothetical terminal and hence the authority imposes a requirement of goods loading/unloading speed of at least 25 containers in an hour per crane on the operator. Any failure to do so might induce traffic jams on waterways, leading to loss of revenue of the authority from port dues. In this case, the operator is required to cover the loss experienced by the authority.

7.7 Discussion on the Applicability of the Climate Risks and Responsibilities Allocation Matrix

As shown in Table 7-1, the application of the proposed measures for allocating climate risks and responsibilities in landlord container terminals is reliant on the knowledge of (1) the frequency of occurrence and/or the consequences of each of the unmitigable and unmitigated climate risks and (2) the extent to which each climate resilience requirement is achieved. Firstly, the contractual protection for each climate risk that is unmitigable or is left unmitigated has to be changed once its thresholds of likelihood and/or consequences are reached. Secondly, to ensure the effectiveness of the allocation of responsibilities for building climate resilient container terminals, the pre-agreed penalty should be imposed once any responsible party fails to meet its obligations. Therefore, an accurate monitoring system or framework for the relevant threshold variables and resilience levels is essential to support the implementation of the developed allocation matrix. Moreover, the methods for measuring the variables and resilience levels should be approved by all port stakeholders beforehand to avoid any dispute in the risks and responsibilities allocation. However, because of the time restriction of the research, the design for the monitoring framework and measurement methods was not addressed in this research.

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Part V

Conclusions and Recommendations

Chapter 8 - Conclusions and Recommendations

Adapting ports around the world to climate change sufficiently is essential to continuously support global trading, which is currently one of the engines of global economic growth. Even though a majority of port stakeholders are aware of the potential negative impacts of climate change on ports, a significant portion of them claim that it is still too early to adapt their ports to the change. This study aimed to address three barriers that have hindered port stakeholders to perform sufficient climate adaptation measures for their ports, which are (1) unavailability of an effective general best practice of climate adaptation for ports, (2) uncertainty regarding the viability and efficiency of climate adaptation investments in ports and (3) unclarity about which port stakeholders are responsible for financing the adaptation. Using the landlord container terminal as a unit of analysis, the following main research question was probed:

Under what conditions and how can viable and efficient investments in climate resilient ports be achieved?

Climate Risks, Opportunities and Adaptation in Ports

The first step to ensure the viability and efficiency of investments in climate resilient ports is to acknowledge the significant climate risks and opportunities, as well as the effective and feasible climate adaptation measures for ports. The outcomes of an extensive literature review of climate adaptation in ports suggest that climate risks and opportunities for container terminals can be classified into potential direct and indirect impacts of climate change on operational, financial, environmental and social performances of the terminals. On one hand, direct impacts consist of effects that directly influence any of the performance indicators, both positively and negatively. They include climate change impacts of sea level rise, higher rainfall, snowfall and hail, as well as more frequent and more intense storm events, winds, waves, lightning, fogginess, cold, drought and heat. On the other hand, indirect impacts encompass effects on the global economy and commodities production, which could lead to higher or lower terminal demand/call.

Moreover, the review found that climate adaptation measures for ports have been discussed in detail in the scientific community and some ports have developed adaptation plans for their ports. Therefore, the potentially effective climate adaptation measures for a container terminal could be determined by (1) exploring relevant literature of climate adaptation in ports and (2) learning from climate adaptation plans and/or practices in terminals that share similar climate risks.

Evaluating the Viability and Efficiency of Climate Adaptation Investments in Ports

Once the effective and feasible adaptation measures for a port are identified, the significant risks should be valued in monetary terms and incorporated into the port business model. Otherwise, it would be impossible to effectively assess the viabilities and efficiencies of different investment options for adapting the port to climate change. An exploration of financial methods suitable for performing such assessment and a fictitious case study on TMMeB indicated that an integration of Weather-VaR and ROA has potential to approximate the viable and efficient option for financing climate adaptation in a port.

Financing Climate Adaptation in Ports

To completely answer the main research question, it is also important to recognize the appropriate financer for each adaptation measure. Otherwise, no investment might be driven for the measures and therefore they would not be successfully translated into actions. By reviewing (1) the existing contractual protections against climate risks in landlord container terminal partnerships and (2) the barriers to incorporate effective allocation of climate risks into the partnerships, the research infers that the responsible financer could be effectively determined if the stakeholder in charge of dealing with each climate risk is explicitly specified in the partnership agreements.

The assignment could be done in two complementary ways. Firstly, all unmitigable and unmitigated climate risks can be classified into relief, compensation, force majeure, insured and uninsurable events, which are the existing types of contractual protections against climate risks in public-private partnerships. To ensure the effectiveness of the protections during the partnerships, the appropriate thresholds of likelihood and/or consequences for each of them could be specified. In this way, once any threshold is reached, the contractual protection applicable to the relevant risk can be altered to a more appropriate one through either variation or renegotiation clause. Secondly, for all climate risks that would be mitigated during the partnerships, the required climate resilience levels for each port infrastructure and operation against them could also be incorporated into the partnerships. Further, the parties in charge of delivering such performances and any penalty imposed on them for failing to meet their obligations have to be clearly stipulated.

Answering the Research Question

Based on the findings of this research, the following climate risk management practices in ports are found beneficial for achieving viable and efficient investments in climate resilient ports:

I. The significant climate risks and opportunities in ports, as well as the port sub-operations and assets susceptible to the risks should be recognized.

II. From the knowledge of the potentially affected sub-operations and assets, effective and feasible adaptation measures for the ports have to be determined.

III. The significant climate risks, as well as the effective and feasible adaptation measures should be valued in monetary terms and incorporated into the port business models.

IV. Based on the outcomes of the assessments, all identified climate risks should be classified into (1) climate risks that are unmitigable or are left unmitigated and (2) those would be mitigated during port partnerships.

V. For all unmitigable and unmitigated climate risks, they shall be classified into relief, compensation, force majeure, insured and uninsurable events.

VI. To ensure the effectiveness of the contractual protections during the partnerships, the protection applicable to each of the unmitigable and unmitigated climate risks should be altered once it is no longer appropriate.

VII. For climate risks that would be mitigated during the partnerships, the required climate resilience levels and the port stakeholders in charge of delivering such performances have to be clearly stipulated.

Policy Implications and Recommendations for Development of Climate Resilient Ports

From the research outcomes, in particular the answers to the research question, the following six recommendations were derived to achieve viable and efficient investments in climate resilient ports (actors indicated in bold):

I. **All port stakeholders** are suggested to join hands for conducting system-based and integrated assessments of climate risks and opportunities for their ports to identify port sub-operations and assets vulnerable to the risks.

II. **Port authorities** and **all other port stakeholders whose operations and assets are potentially affected by the identified climate risks** are encouraged to explore the effective and feasible climate adaptation measures for their vulnerable operations and assets.

III. **Port authorities** and **the other potentially affected port stakeholders** are advised to value the risks in monetary terms such that they are incorporable into their business models. In this way, the viable and efficient climate adaptation investment options for their ports can be approximated.

IV. **Port authorities** and **the other potentially affected port stakeholders** are recommended to categorize climate risks in their ports into two classifications of (1) climate risks that are unmitigable or are left unmitigated and (2) those would be mitigated during their partnerships. The following set of decision rules could be employed for classifying the risks:
   - Climate risks without any effective and feasible adaptation measure can be classified as unmitigable risks.
   - Climate risks with no viable investment option to execute their corresponding effective and feasible adaptation measures can be considered as the risks that are left unmitigated.
   - Climate risks with viable investment options to execute their corresponding effective and feasible adaptation measures can be categorized as those would be mitigated.

V. **Port authorities** and **all other port stakeholders potentially affected by the unmitigable and unmitigated risks** are suggested to assign each of the risks into the currently suitable contractual protection type. Moreover, to address the issue of rising unmitigable and unmitigated risks, the appropriate thresholds of likelihood and/or consequences for each of them could be incorporated into the partnerships. Further, they are encouraged to make pre-agreements on how the transition of contractual protection applicable to each risk should be performed once any of the relevant thresholds is reached.

VI. As governors of operations in landlord ports, **port authorities** are advocated to take the lead role in discussing the responsibilities for mitigating climate risks that would be reduced and/or eliminated during port partnerships with **other port stakeholders**, and explicitly allocate the responsibilities afterwards.

Research Contributions for Landlord Container Terminals

The outcomes of this research could be expected to assist stakeholders of landlord container terminals in carrying out some of the recommended actions. Firstly, the developed climate risks and opportunities assessment matrix could facilitate them in performing the suggested system-based and integrated evaluations. Secondly, the established framework for assessment of the viabilities and efficiencies of different climate adaptation investment options in ports has potential for approximating the viable and efficient investment option for adapting a container terminal to climate change. Thirdly, the constructed climate risks and responsibilities allocation matrix could be employed for addressing the need for explicitly stating which port stakeholders are in charge of (1) financing the financially viable climate adaptation measures and (2) recovering terminal operations and assets following the materialization of any of the unmitigable and unmitigated climate risks.

Scientific Contributions of the Research

Apart from the practical contributions, the research has also delivered additional insights and discussions to the scientific community. Firstly, it has the potential to enhance climate risks and opportunities assessment matrix for ports. As shown in Stenek et al. (2011, p. 182-185), the existing matrix presents climate risks and opportunities at an aggregate level of whole port operations. Therefore, it can only indicate the significant risks and opportunities, but it does not explicitly inform which sub-operations and assets are susceptible to the risks. In this research, a system-based and integrated approach, which considers the potential impacts of climate risks on each sub-operation and asset essential for the functioning of ports, was incorporated into the matrix. Hence, it allows the users to identify not only the significant risks and opportunities for their ports, but also their vulnerable sub-operations and assets. In this way, climate adaptation measures for ports could be identified in an enhanced manner.

Secondly, the research offers new insights for extending the application of Weather-VaR. To the knowledge of the author, this research is the first one that attempts to integrate the method with other existing financial method. By incorporating Weather-VaR and ROA into one practice, the viabilities and efficiencies of different climate adaptation investment options can be estimated. Therefore, the viable and efficient option for investing in climate adaptation could be approximated.

Finally, it introduces dynamic adaptive concept into the contractual protections against climate risks in public-private partnerships, which are currently rigid in practice. According to Sundararajan and Suriyagoda (2016), stiff classification of climate risks into different contractual protection types in the partnerships is inappropriate to deal with uncertain and dynamic pace of climate change. This research proposes a methodology to transform the firm contractual protections into adaptive ones. The conversion could be achieved by (1) specifying the appropriate thresholds of likelihood and/or consequences for each of the unmitigable climate risks and those left unmitigated and (2) including variation or renegotiation clause for each of them into the partnership agreements. Therefore, once the threshold of any of the unmitigable and unmitigated climate risks is reached and hence its original contractual protection is no longer effective, the protection could be shifted to a more appropriate one through either variation or renegotiation clause. In this way, the effectiveness of all contractual protections against climate risks could be ensured throughout the partnerships.

Chapter 9 - Limitations and Future Research

Several research limitations have been described in the previous chapters. All of them arise because of (1) restrictions on the research scope resulting from time constraints in the project and (2) limitations in the research outcomes. In this chapter, they are revisited and expanded to incorporate relevant researches currently conducted by the fellow students in Deltares. Moreover, based on the presented limitations, directions for future research are discussed.

9.1 Limitations in Research Scope

I. In this research, only the container terminal business unit of a port is analyzed. Although the outcomes are promising, it is very beneficial to explore their transplantabilities to other business units to fully support the development of climate resilient ports.

II. As discussed in Chapter 3.1, hinterland connections are important for the functionality of ports. Therefore, sustaining them against climate change is also essential. Fellow MSc student M. Tsavdaroglou is currently delving into the issue of climate risks for hinterland transport infrastructures, using the case of the Port of Rotterdam.

III. The potential interaction of weather variables, which would lead to an occurrence of more than one adverse weather event at the same time, has not been incorporated into the developed climate risks and opportunities assessment matrix presented in Chapter 3.2. Similarly, cascading effects of any adverse weather event, in which (1) damage of an asset would lead to damage to other assets and (2) inoperability of a sub-operation would induce inoperability of other sub-operations, have not been explicitly integrated into the matrix. Fellow MSc student R. van Dijk is currently exploring the potential of incorporating them into the assessment using system diagram. Another possible option to analyze the risks of cascading effects is to integrate the matrix with the CIrcle tool developed by Hounjet et al. (2015), which has shown a potential for analyzing the interdependencies among different industries and critical infrastructures.

IV. The climate adaptation measures presented in Chapter 4.2 are still not directly integrated into the developed assessment matrix. In fact, by embedding them into the matrix, the users could identify effective climate adaptation measures for their ports in a timely manner.

V. The presented adaptation measures in Chapter 4.2 are rather generic. Hence, a more detailed assessment of their potential implementations in ports is needed. The gap is partially covered by fellow MSc student J. Mol, who is exploring potential Building with Nature options for adapting the Port of IJmuiden to climate change.

VI. As presented in Chapter 5.4, this research only provides insight into the financial impacts of climate change on ports and the financial contributions of the proposed climate adaptation measures. However, the non-financial impacts and contributions have not been evaluated in detail. Consequently, it cannot be claimed with certainty that the recommended climate adaptation investment options in ports will ensure maximization of overall social welfare. In this regard, it is advantageous to assess the suitability of the developed assessment framework for evaluating the viability and efficiency of climate adaptation investments in ports from societal perspective. This could be accomplished by applying the framework to several ports whose developments and operations have been evaluated by Social Cost-Benefit Analysis.

VII. The principal-agent problem that hinders effective climate risks and responsibilities allocation in landlord ports has not been addressed in this research. Therefore, answers to the question of *"How to incentivize* *private port contractors and operators such that their actions are in line with the interests of the port authority?*" are required to further enhance the effectiveness of the allocation.

VIII. The developed framework for assessment of the viability and efficiency of climate adaptation investments in ports has not been linked to the proposed climate risks and responsibilities allocation matrix. In fact, both of them could be connected because investment options in landlord ports can consist of not only different adaptation levels but also different financers. As port authority and private sector possess distinct discount rates and different assessment time horizons, the viabilities and efficiencies of various feasible adaptation levels are likely to be dissimilar when they are assessed from different perspectives. In this regard, the question of *"How to allocate the responsibilities for adapting ports to climate change by taking into account different discount rates and dissimilar investment time horizons of port stakeholders?"* is worth exploring.

9.2 Limitations in Research Outcomes

I. Two main simplifications were made in the case study of TMMeB, which are: (1) the terminal is operated for 24 hours a day and (2) the flow of goods in the terminal is uniform throughout a day. They were employed because of the absence of extensive sea level modeling in this research, which leads to inability of determining at which hours in a particular year are the causeway flooded. In fact, based on the historical sea level data extracted from University of Hawaii Sea Level Center (2016), the contributions of (1) astronomical tide, (2) seasonal variation and (3) storm surges could be segregated in a later project. In that way, the sea level at any hour in a particular year could be acknowledged with enhanced accuracy. Therefore, by modeling the sea level thoroughly, the actual operating hours and the variance in goods flow within a day can be incorporated into the assessment.

II. The outcomes of the assessment of the viabilities and efficiencies of different climate adaptation investment options for TMMeB are subjected to a key assumption that the only differences between performing one-off and phased adaptation strategies are: (1) a significant portion of variable costs of the adaptation can be delayed to the future by performing the latter strategy, (2) the fixed cost of adaptation has to be paid for several times if the phased strategy is selected, while it is only borne once in the case of one-off adaptation. However, in reality, additional benefits offered by one-off adaptation and additional costs for implementing the phased adaptation may exist. For instance, by performing a sufficient one-off adaptation at the very beginning, the reputation of the terminal could be enhanced, leading to increase in the terminal demand/call and hence higher financial profits for the stakeholders. Such factor, which is difficult to be quantified with acceptable accuracy, could be significant and therefore would negatively affect the accuracy of the assessment. In this regard, an exploration for incorporating the intangible benefits and costs into the evaluation is beneficial. Otherwise, the practicality of the assessment would be questionable.

III. The selected case for the quantitative case study might be too simple as TMMeB is only subjected to the risks induced by average sea level rise. To further assess whether the framework is still applicable for ports exposed to numerous climate risks, additional case studies are recommended. One of the potential ports to be analyzed is Port of Manzanillo, which faces risks from higher precipitation, more frequent and more intense storms, as well as average sea level rise. Moreover, the outcomes of climate risks and opportunities assessment for the port have been recently published. The assessment advises 21 adaptation measures for Port of Manzanillo.

IV. As discussed in Chapter 7.7, an accurate and acceptable monitoring system or framework for evaluating (1) the likelihood and/or consequences of each of the unmitigable and unmitigated climate risks and (2) the achieved climate resilience levels is imperative to support the implementation of the proposed climate risks and responsibilities allocation matrix. Therefore, a dedicated research to design the required monitoring system is highly recommended.

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Appendices

Appendix A - Port Governance Models

Because of the growth of capitalism and its desperate attempt to find more places to reinvest the growing surplus capital, a vast wave of privatization continues to occur around the world (Harvey, 2010), including in port operations. Privatization, either full privatization or partial privatization (i.e. devolution), in ports occurs mainly as a result of the growing need for operational efficiency. The increasing port competitions for cargos and transhipment trades require ports to maintain or enhance their competitiveness in operational efficiency, pilotage costs, harbour dues, storage fees, etc. (Tongzon & Heng, 2005). In this case, ports become business itself and privatization of port operations is a logical step to achieve the required efficiency level and competitiveness (Ligteringen & Velsink, 2012).

The more intense competition between ports brings two side effects. On one hand, it stimulates efficiency and keeps the port fees and service costs down. Previously, in the absence of competition, it was in the interest of port stakeholders to provide port services efficiently at minimum costs. However, they failed to achieve those goals as their behaviours were transformed to money earners through their monopoly powers. On the other hand, excessive competition may lead to overcapacity and losses that in most cases paid by public (Ligteringen & Velsink, 2012). Moreover, unfair competition may arise and should be avoided as it leads to price distortion and therefore reduces the social welfare.

Privatization and devolution processes in ports are also supported by other factors, which include (1) improvement in information technology, which has increased the transparency of government operations and hence provided public with higher ability to oversee and participate in government activities, (2) increasing trade and budget deficits, as well as accumulated sovereign debt burdens, which force governments to sell their assets and find ways to do more with less financial resources (i.e. funds) (Aerts et al., 2014). Nowadays, as a consequence of the privatization and devolution processes in port sector, there is hardly any port where public port authority is responsible for the whole port operations. Very often, goods handling and storing, as well as ground transportation sub-operations are performed by private port operators. Private port operators are specialized in those sub-operations and therefore can provide better services at lower prices compared to port authorities.

Apart from public port authority and private port operators, there are also other stakeholders that indirectly involve, but play important roles in port operations. They include (1) forwarders, whose business is to perform hinterland transportation of goods between ports and production/consumption centers (Córdova & Durán, 2014), (2) shipping agents, who arrange shipping lines between seaports, allocate shipping spaces on vessels, prepare shipping documents and deal with custom requirements (Ligteringen & Velsink, 2012), (3) shipping companies or shippers that execute the transhipment process. Nowadays, several forwarding firms have been expanded to include the service provided by shipping agents. For instance, Kerry Logistics has a global network with major ocean carriers while at the same time providing hinterland transportation services for its customers or clients. The roles of the discussed external port stakeholders are depicted in Figure A-1.

As port organizations and relationships between port stakeholders have been evolved in the past decades, several attempts have been made to classify them into different port types. In this appendix, the model offered by The World Bank (2007) in its World Bank Port Reform Toolkit, which is perhaps currently being the mostly used by port practitioners for classifying port management systems, is elaborated. The World Bank suggests that port governances across the globe can be grouped into four types, which are (1) service port, (2) tool port, (3) landlord port and (4) private port. The institution argues that the choice of governance type in each port is influenced by the way it is organized, structured, managed, located, as well as its historical development, types of commodities served and other socio-economic factors (Brooks, 2004).

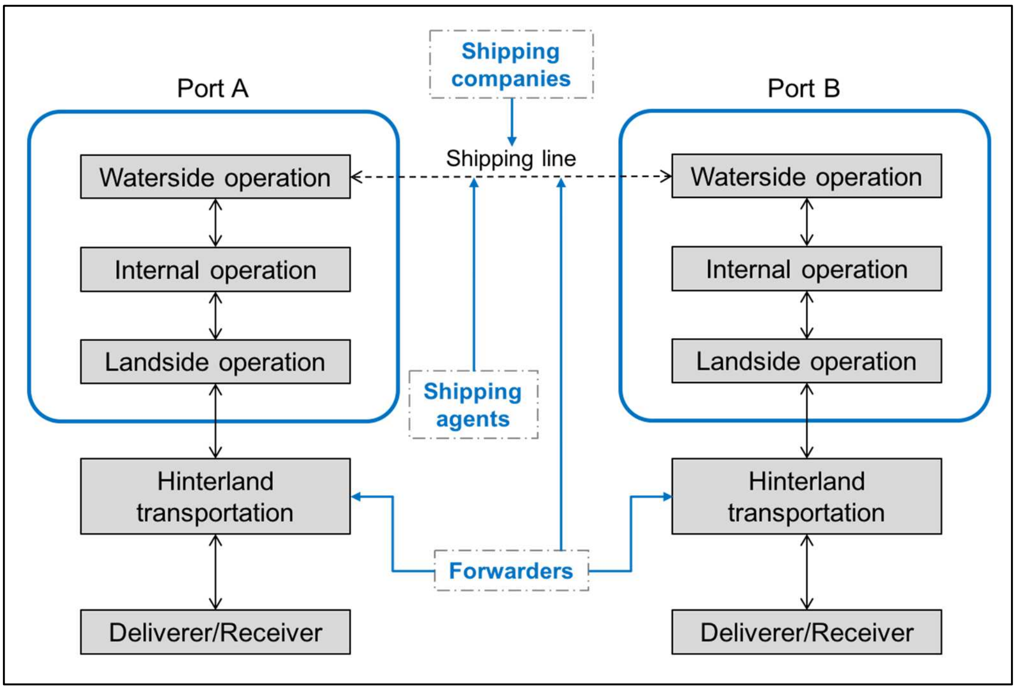


Figure A-1: Roles of external port stakeholders in goods shipment

A.1 Service Port

In a service port, the government or public port authority owns, operates and maintains all port assets in support for port operations. All labors in charge of operation and maintenance of port assets are directly employed by the authority. This governance model was common prior to the waves of privatization and devolution, but the number continues to decline as most of the remaining service ports are currently in transition towards a landlord port structure (The World Bank, 2007). The port type allows a cohesive approach to growth as all responsibilities for port operations and development belong to one entity only. However, the absence of internal competition in port operations may lead to inefficient operation and failure in meeting the dynamic market demands.

Text Box A-1: Port of Cirebon, Indonesia

The Port of Cirebon is situated in the north coast of Java Island, Indonesia. It is now served as an alternative port to Port of Tanjung Priok, the largest port in Indonesia, which is currently facing an operational inefficiency problem (Artakusuma, 2012; Rizkikurniadi & Murdjito, 2013). Most of the port activities consist of handling bulk imports of coal, liquid asphalt and vegetable oils for the West Java hinterland. The port is owned by the Government of Indonesia and operated by the state-owned corporation of Indonesia Port Corporation (Indonesia Port Corporation, 2012).

A.2 Tool Port

In a tool port, the public port authority remains responsible for providing the essential infrastructures (e.g. waterways, quays and yards), superstructures (e.g. quay cranes) and ground vehicles. The operations of those superstructures and ground vehicles are generally carried out by private stevedoring firms under licenses granted by the authority. This port type avoids any duplication in port assets as all of them are provided by the authority. However, the separation between ownership and operation of superstructures and vehicles for goods handling, goods storing and ground transportation sub-operations could lead to conflict between the authority and stevedoring firms.

Text Box A-2: Port of Chittagong, Bangladesh

The Port of Chittagong is the busiest container port in Bangladesh. In 2005, the port handled about 90% of the national foreign trades. However, the port is currently facing a low productivity issue and the slow turnaround time is expected to negatively impact the national economy. The Chittagong Port Authority is the overall administrator of the port, who is responsible for the management, coordination, future planning and providing some port services (Shahjahan, 2000). Goods handling and storage, as well as ground transportation sub-operations are mostly performed by stevedores hired by shipping agents, who are granted by the port authority to provide relevant labors (The World Bank, 2005).

A.3 Landlord Port

In a landlord port, the public or semi-private port authority acts as the landowner and grants concession to one or more private port operators to execute goods handling, goods storing and ground transportation within the terminal for a certain time period. According to Notteboom (2007), in the context of brownfield development (i.e. addition to the existing port infrastructures), concession usually takes the form of long-term lease. In such contract, the public authority is responsible for providing and maintaining port waterways and other main infrastructures, while private operators are allowed to perform goods handling, goods storing and ground transportation sub-operations using their own superstructures and vehicles, as well as extracting revenues from their operations. In return to the given concession, the operators are required to pay concession fees to the authority regularly. The superstructures can be held by the authority with or without payment in the end of the long-term lease contract, depending on the stipulated agreement between the authority and the operators. In this case, the public-private partnership model can be classified as an Equip-Operate-Transfer (EOT) one (The World Bank, 2007).

Text Box A-3: Port of Tanjung Priok, Indonesia

The port is handling more than 50% of annual Indonesian transhipment cargos. Its operation is infamously known as one of the least efficient in South East Asia, with an average turnaround time of 6 times of that in the Port of Singapore (Artakusuma, 2012; Rizkikurniadi & Murdjito, 2013). The port is a property of the Indonesian government and currently being operated by two firms, which are Indonesia Port Corporation and Hutchinson Port Holdings. The private holdings entered the port through an EOT agreement with the state-owned firm and it installed new equipment and provided training to improve the crane efficiency from 18-19 moves per crane per hour in April 1999 to 24-25 moves per crane per hour in late 2000 (Ray & Blankfeld, 2002).

In new terminal or port development (i.e. greenfield development), more options are feasible to allocate the responsibilities for designing, constructing, financing the construction and operating the terminal between port authority and private sector. In general, the authority provides new development areas or lands to the private sector, while at the same time still in charge of providing and operating navigable waterways. The private sector is responsible for developing the relevant port infrastructures (e.g. quays, seawalls and pavements) and equipping them with the relevant superstructures and equipment in support for port operations. In most cases, during the contract period, the infrastructures are owned by the authority, while the superstructures and equipment are under possession of the private sector. As discussed in Notteboom (2007), the commonly applied partnership options in greenfield development of landlord ports include the followings:

1) **Build – Lease – Operate (BLO)**
The authority leases the construction and operation of a terminal to a private consortium or Special Purpose Company (SPC) through a long-term partnership. The private actor constructs the terminal using funds provided by either the authority, consortium, or both, and operates it afterwards. The authority owns the right of the

terminal throughout the partnership period and requires lease fee payment from the consortium or company regularly. This type of project financing is commonly applied in port development projects in China.

Text Box A-4: Fuzhou Port, China

To meet the increasing demand of bigger containerships, reducing freight rates and stimulating container growth, the Fuzhou Port Authority created a joint venture with PSA Corporation Limited in April 1998 (UNCTAD, 1998). The deal requires the corporation to (1) manage and operate the existing Qingzhou and Taijiang container terminals, (2) study the feasibility of developing a new deep-water container terminal in the port, (3) perform the construction of the terminal and (4) manage the operations of the terminal afterwards (Bangsberg, 1999a; Bangsberg, 1999b; UNCTAD, 1998).

2) Build – Operate – Transfer (BOT)

The port authority grants a concession to a private firm to design and construct a new terminal, finance the construction, operate the terminal and obtain revenues from the operation afterwards within an agreed time period stipulated in the contract. Therefore, under BOT contract, all risks of construction and operation of the terminal are transferred to the private sector during the partnership. At the end of the partnership, the authority retains all of the operations and pre-agreed assets. It is currently the most popular public-private partnership option for greenfield development of port terminals (Aerts et al., 2014; Notteboom, 2007).

Text Box A-5: Nhava Sheva International Container Terminal, India

The terminal is the first private container terminal and one of the most modern terminals in India. Its development was executed by P&O Ports (now: DP World Limited) in 1997 under a 30-year BOT agreement with the Government of India at a cost of USD 200 million (DP World Limited, 2013). The private firm completed the construction before the schedule and commenced its operations in 1999 (India. Ministry of Finance, 2010). The private participation in port operations results in an impressive gain in operational efficiency. For instance, the average turnaround time in 2003-2004 for containers was 1.84 days, which was far superior as compared to those in comparable terminals operated by public sector (UNESCAP, 2008).

3) Build – Rehabilitate – Operate – Transfer (BROT)

The project financing agreement in form of BROT is analogous to the BOT agreement. However, the main aim of the project under BROT is to build an add-on to the existing facility, rehabilitate, retrofit, or upgrade an existing port terminal. After the terminal is completed or modernized, the private consortium or company is entitled to operate the terminal and gain revenue from the operations. In the end of the concession, the upgraded terminal and its operations are retained back by the port authority.

Text Box A-6: Port Klang Container Terminal, Malaysia

According to UNESCAP (2008), Port Klang is a good example of BROT project financing agreement in transportation sector. In 1986, an award of 21-year contract was given by the Port Klang Authority to a new private terminal operator named Klang Container Terminal (KCT). The contract allows the operator to enhance, manage and operate container facilities in Port Klang. The contract was indeed a result of the privatization program initiated by the Government of Malaysia. The key driver for the privatization was the low operational efficiency in the terminal, as compared to the international standard (UNESCAP, 2008). According to the privatization plan of the terminal, the shares of KCT were distributed as follows: (1) new private operator – 40% of the shares, (2) general public – 35% of the shares, (3) Port Klang Authority – 20% of the shares and (4) employees of KTC – 5% of the shares (Havelka, 1990).

4) Build – Operate – Share – Transfer (BOST)

BOST project finance agreement is very similar to the BOT one, except for the fact that the revenue obtained by the private operator has to be shared with the port authority during the concession period. The sharing requirement is generally stipulated in the contract between the authority and the operator.

Text Box A-7: Krishnapatnam Port, India

Andhra Pradesh region was one of the first port cities in India that recognize (1) the need for enhanced port equipment and (2) the benefits that could be brought by private sector. The privatization of Krishnapatnam Port was conducted through a BOST agreement. The BOST contract between the Government of Andhra Pradesh and Krishnapatnam Port Company Limited stipulates that (1) the company is granted for a concession of 30-year that can be extended by 2 more spells of 10 years each, (2) the revenue from port operations has to be shared with the government at a progressive rate, in which it was set to be 5% in the first five years and 12% in the later years and (3) at the end of the concession, immovable assets are transferred to the government at no cost (The Government of Andhra Pradesh, n.d.).

Landlord port type avoids any potential conflict between port stakeholders because the operations and ownerships of internal assets are held by a single entity of private company or consortium within its concession period. However, it could lead to a risk of overcapacity as one or more stakeholders may pressure for capacity expansion. According to Ligteringen and Velsink (2012), as of 1997, 88% of top 100 container ports across the globe belong to landlord port. As previously discussed, the port type is widely implemented nowadays because of the need for enhanced operational efficiency of ports, which are provided by private port operators. Moreover, increasing public deficit and the adoption of austerity measures have forced many governments to grant port operations and new developments to private sector (Aerts et al., 2014).

A.4 Private Port

In a private port, a private firm or consortium owns, operates and maintains all port assets, including the land of the terminals. Statutory functions, such as navigation and safety, environmental protection and customs still remain under strict control of the relevant government authorities. The port type is very likely to lead to flexible port operations and hence market-oriented services and tariffs. However, monopolistic behavior or cartel (i.e. illegal agreement between private port operators) may appear and cause significant loss in public welfare. Moreover, public involvement in developing long-term economic policies and strategies relevant to maritime transportation is diminished.

According to Baird (2000), one of the most common methods employed to bring about port privatization is executing a public-private partnership that transfers the ownership of the port to private sector for a certain time period or continuously. Examples of such partnership are as follows:

1) Build – Own – Operate – Transfer (BOOT)

Under BOOT scheme, a private corporation or consortium finances the construction of the terminal, owns the terminal, possesses the right to operate the terminal and gains revenue from the operations within an agreed time period. In the end of the agreement, all of the assets are transferred to the authority for free or at a pre-agreed price (The World Bank, 2007). As the ownership of the terminal is also transferred during the concession period, the port can be considered as a private one within the period.

2) Build – Own – Operate (BOO)

The project financing agreement of BOO is similar to that of BOOT, but the developed terminal is not transferred to the public port authority at all. Therefore, since the construction begins, the port can be classified as a private port.

Apart from the public-private partnership channel, privatization can also be done by directly auctioning ports to private sectors, such as in the case of ports in the United Kingdom (Baird, 2000).

Text Box A-8: Associated British Ports Holdings, United Kingdom

The private holdings is currently owning and operating 21 major ports in the United Kingdom, which is approximately equivalent to 25 percent of the national sea-borne trades. Since 2006, it is owned by a consortium of Goldman Sachs, Borealis, GIC and Prudential. The holdings obtained the ports by purchasing them from the government, which was critized for selling the infrastructures at highly discounted prices (Baird, 2000). As the market share of the holdings grows, competition between ports in the nation becomes less intense, which could later lead to monopolistic behaviour of the holdings. In this case, the goal of enhancing competition among ports that result in benefits flowing to port users could fail (Baird, 2000).

A.5 Summary of Roles of Public and Private Sectors in Different Port Governance Models

Based on the aforementioned descriptions of different port types, the distribution of responsibilities for asset ownership and operation between public and private sectors in different port governance models can be determined, as tabulated in Table A-1. As argued by Baltazar and Brooks (2001), the allocation of responsibilities in each sub-operation differs from nation to nation. Therefore, in Table A-1, each of the presented sectors refers to port stakeholder that plays higher role in the ownerships or operations of the relevant assets, but not necessarily the only sector that owns or operates the assets. For instance, as previously discussed, Port of Tanjung Priok, which is regarded as a landlord port, is currently being operated by both public and private sectors. However, the private sector (i.e. Hutchinson Port Holdings) can be considered to play a larger role in goods handling as it provides quay cranes and the operators.

Table A-1: Distribution of responsibilities for asset ownership and operation in different port governance models

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="6">Port sub-operations</td></tr>
<tr><td>Navigation</td><td>Berthing</td><td>Goods Handling</td><td>Ground Transportation</td><td>Goods Storing</td><td>Connection to Hinterland Connection</td></tr>
<tr><td rowspan="8">Port types</td><td rowspan="2">Service</td><td>Main Assets Owner</td><td colspan="6" rowspan="2">Public</td></tr>
<tr><td>Main Assets Operator</td></tr>
<tr><td rowspan="2">Tool</td><td>Main Assets Owner</td><td colspan="6">Public</td></tr>
<tr><td>Main Assets Operator</td><td colspan="2">Public</td><td colspan="3">Private</td><td>Public</td></tr>
<tr><td rowspan="2">Landlord</td><td>Main Assets Owner</td><td colspan="2" rowspan="2">Port authority*</td><td colspan="3">Port authority* for infrastructures
Private for superstructures and vehicles</td><td rowspan="2">Port authority* and/or Private</td></tr>
<tr><td>Main Assets Operator</td><td colspan="3">Private</td></tr>
<tr><td rowspan="2">Private</td><td>Main Assets Owner</td><td colspan="6" rowspan="2">Private</td></tr>
<tr><td>Main Assets Operator</td></tr>
</table>

* Port authority can be either a public or semi-private entity in a landlord port.

Appendix B - Description of Unselected Variants of Real Options Analysis

As discussed in Chapter 1.5, (1) decision tree analysis, (2) Binomial Option Pricing Method, (3) Black-Scholes Option Pricing Model and (4) spreadsheet analysis variants of Real Options Analysis (ROA) have been applied for valuing options in engineering projects. In the end, the last variant was found to be the most suitable one for developing an assessment framework of viability and efficiency of climate adaptation investments in ports. While the selected variant has been described in Chapter 5.2, the remaining variants are briefly elaborated in this appendix.

B.1 Decision Tree Analysis

ROA is grounded on decision tree analysis, which is still considered to be one of the most important tools that take flexibilities, which are left out from the standard discounted cash flow analysis, into account. Since decision tree analysis was found, it has been remaining as an important tool for investment decision. In summary, the analysis is a tool that shows strategic future pathways that investors can take based on a number of different possible future scenarios. Its application is suitable when (1) possible future conditions, (2) the probability of occurrence of each possible future state and (3) the returns of different investment options in each future state are known with considerable accuracies.

According to de Neufville (1990), a decision tree is composed of three basic nodes, which are (1) decision nodes, where possible decisions are presented and a decision has to be made, (2) chance nodes, where outcomes of different investment options are determined by probabilities of occurrences of possible future conditions and (3) terminal nodes, where an investment or project is completed. By assigning probabilities and payoffs in all chance nodes and terminal nodes, respectively, the value of each decision can be evaluated as the sum of products of probabilities and payoffs of all possible future outcomes of the decision.

For instance, consider a hypothetical port whose operations are at high risk of storm surge. The frequency of such adverse event is still expected to be very rare, such as once every 10 years (i.e. a probability of occurrence of 0.1 in a year, approximately). As shown in Figure B-1, the port is facing two options of (1) taking a preventive measure of raising the port and (2) do nothing. The cost of raising the port is assumed to be 100, while the reduction in net annual cash flow in case of any storm surge event is expected to be 350. Therefore, the benefit gained from raising the port is 250 if any surge occurs in a particular year. From these assumptions, the payoff of each option can be determined, as presented in Figure B-1. The values of the options of “raise the port” and “no action” are therefore -65 and -35, respectively. By comparing the values, it can be concluded that the option of “no action” prevails.

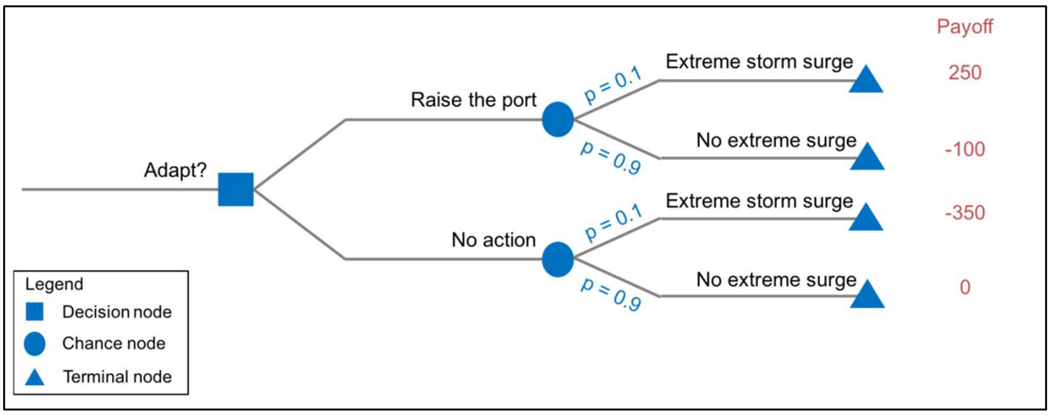


Figure B-1: An example of decision tree analysis of a climate adaptation measure for a hypothetical port

B.2 Binomial Option Pricing Method

Binomial Option Pricing Method employs a discrete time process. In summary, it is based upon an assumption that the price of an asset can move either (1) upwards with an up factor of u and probability of p or (2) downwards with a down factor of d and probability of $1-p$ at any time interval (Cox et al., 1979). A binomial tree can be used to illustrate how the asset price evolves with time, as shown in Figure B-2. A formula derived from Geometric Brownian Motion is used to compute the value of each option associated with the asset price. The main variable that has to be estimated for employing the method is the volatility of the asset price. As presented in Cox et al. (1979), the equations generally used for computing the up and down factors are $u = e^{\sigma\sqrt{h}}$ and $d = e^{-\sigma\sqrt{h}} = 1/u$, where σ is the volatility of asset price and h is the time interval between asset price movement.

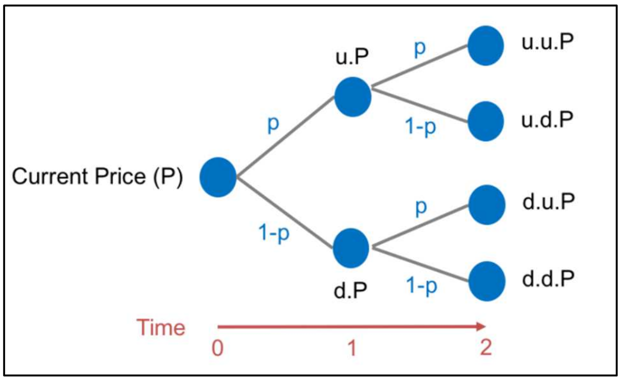


Figure B-2: An illustration of the evolution of asset price with time in Binomial Option Pricing Method

B.3 Black-Scholes Option Pricing Model

Black-Scholes Option Pricing Model is perhaps the most popular method for evaluating the price of a financial option in financial market. The model was developed in the early 1970s by Fischer Black, Myron Scholes and Robert Merton, and it was considered as a major breakthrough in derivative pricing (Black & Scholes, 1973). The mathematical model offered by them can be considered as a closed-form solution, which is a mathematical equation that can be solved using a set of assumptions for some input variables. The model has been widely used to assess the value of financial options, such as the price of a European call option on a dividend-paying stock. According to Hull (2003), the price of the option can be modelled as:

$$C_0 = S_0 . e^{-qT} . N(d_1) - X . e^{-rT} . N(d_2), \text{ where } d_1 = \frac{\ln(S_0/X) + T.(r - y + \sigma^2/2)}{\sigma\sqrt{T}} \text{ and } d_2 = \frac{\ln(S_0/X) + T.(r - y - \sigma^2/2)}{\sigma\sqrt{T}}$$

In the formula, C_0 represents the price of the option, S_0 refers to the current price of the stock associated to the option, q indicates the continuous compounded dividend rate of the associated stock, T is the time to maturity of the option, $N(.)$ represents the cumulative probability distribution function for a standardized normal distribution, X indicates the strike price of the option (i.e. the price at which the owner of the option can buy/sell the stock associated to the option), r is the risk-free interest rate, y is the dividend payout rate and σ is the standard deviation of annual return of the stock.

According to Eschenbach et al. (2007), real options in engineering projects have many differences compared to financial options, which is the general habitat of both Binomial Option Pricing Method and Black-Scholes Option Pricing Model. Firstly, in engineering projects, there is no existence of market that sells and buys the project as active as the trading market for financial options. Secondly, engineering projects, especially in the context of dynamic climate, may include many uncontrolled (i.e. external) variables, such as climate variables, economic growths, while stock price is the only uncontrolled variable in financial options. Lastly, the existence of an open market for financial options allows one to prove the validity of financial options valuation and pricing. In contrast, the inexistence of market for real options in engineering projects implies that proving the validity is difficult or rather impossible. Eschenbach et al. (2007) conclude that both Binomial Option Pricing Method and Black-Scholes Option Pricing Model are not better than discounted cash flow analysis for accounting uncertainty in parameters of engineering projects. The recognition of the value of flexibility in decision making is the only benefit offered by the methods.

Appendix C - Climate Risks and Opportunities Assessment Matrix for Container Terminals

Climate Risks and Opportunities Assessment Matrix for Container Terminals

Name of Assessed Terminal	Terminal A

No	Climate Change Impact and Weather Event	Main Type of Risk/Opp. for Terminal*	Main Sub-operation Affected	Relevant Asset(s)	Range/Threshold of Relevant Weather Variables		Relevant Primary Impacts	Risk for Terminal Assets/Operations?		Expected Impact**	Other Sub-operations Affected	Relevant Secondary Impacts		Expected Impact**	Source
					Variable	Range/Threshold	Risks and Opportunities	Assets	Operations			Risk/Opp. Type*	Risks and Opportunities		
1	Impacts of climate change on the economies of the terminal's main trading countries	FIN	All	None	N/A	N/A	• Lower terminal demand/call due to (1) reduction in the production of main export commodities in the regions served by the terminal, such that the export volumes of the regions are lessened and/or (2) increase in the production of main import commodities in the main trading countries, such that their demands for import are reduced.	-	√		All	None	None		Connell et al. (2015), Stenek et al. (2011), USCCSP (2008)
2	Shift in distribution of weather-sensitive commodities (e.g. agricultural, fishery and forest products)	FIN	All	None	N/A	N/A	• Higher terminal demand/call due to (1) increase in the production of main export commodities in the regions served by the terminal, such that the export volumes of the regions are enhanced and/or (2) reduction in the production of main import commodities in the main trading countries, such that their demands for import are enhanced.	-	√		All	None	None		Connell et al. (2015), Stenek et al. (2011)
3	High wave, including that induced by storm	ENV	None	Aquatic vegetations and species	Wave speed	Subjected to the vegetations and species	• Reduction in the habitability of the vegetations and species due to coastal erosion.	√	-		None	FIN	• Higher expenditure for compensating the loss of the vegetations and species. • Higher premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011), USCCSP (2009)
4	High salinity of seawater	ENV	None	Aquatic vegetations and species	ΔSeawater salinity	> 0 ppm	• Reduction in the habitability of the vegetations and species due to salt stress.	√	-		None	FIN	• Higher expenditure for compensating the loss of the vegetations and species. • Higher premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011)
5	High precipitation, including that induced by storm	ENV	None	Aquatic vegetations and species	Rainfall	Subjected to the vegetations and species	• Reduction in the habitability of the vegetations and species due to silt and debris run-off to the vegetation and habitat of the species.	√	-		None	FIN	• Higher expenditure for compensating the loss of the vegetations and species. • Higher premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011)
6	Average sea level rise	ENV	None	Aquatic vegetations and species	ΔWater level	> 0 cm	• Reduction in the habitability of the vegetations and living spaces for species.	√	-		None	FIN	• Higher expenditure for compensating the loss of the vegetations and species. • Higher premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011)
7	High air/sea temperature	ENV	None	Aquatic vegetations and species	Air and sea surface temperature	Subjected to the vegetations and species	• Reduction in the habitability of the vegetations and species whose optimum living temperatures are not high. • Enhancement in the habitability of the vegetations and species whose optimum living temperatures are not low.	√	-		None	FIN	• Higher expenditure or lower expenditure for compensating the loss of the vegetations and species. • Higher premium or lower premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011)
8	High air/sea temperature	ENV	None	Aquatic vegetations and species	Air and sea surface temperature	Subjected to the vegetations and species	• Reduction in the habitability of the vegetations and species whose optimum living temperatures are not low. • Enhancement in the habitability of the vegetations and species whose optimum living temperatures are not high.	√	-		None	FIN	• Higher expenditure or lower expenditure for compensating the loss of the vegetations and species. • Higher premium or lower premium to insure the vegetations and species.		Connell et al. (2015), Stenek et al. (2011)
9	Droughtness [only for inland container terminals]	OPE	Navigation and Connection to hinterland connection	Waterways	ΔWater level	< 0 cm	• Slower marine traffic/Higher terminal downtime as a portion of waterways could be closed during dredging, which is more frequently needed. • Reduction in the size of sea vessels accommodable due to higher restriction in ship navigability. • Lower volume of goods served by the terminal due to reduction in the amount of cargos that can be carried by incoming vessels. It has been estimated that a cargo vessel must reduce its carrying load by 50 - 270 tons for every 2.5 cm decline in the water level. • Increase in terminal downtime during drought or dry period.	√	√		All	OPE	• Inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal.		Stenek et al. (2011)
												ENV	• Off-site and water pollutions due to dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and hence reduction in water quality.		
												FIN	• Lower terminal profit due to slower marine traffic/higher terminal downtime and lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium due to higher dredging costs. • Higher operational expenditure/insurance premium for compensating the loss of the vegetations and species.		
												SOC	• Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		

10	Dust storm	OPE	All	All	Wind speed Visibility level	> 11.5 m/s < 200 m	• Damage to goods stored and other terminal assets if they are not properly stored or lashed. • Higher needs for cleaning the affected terminal infrastructures, superstructures, goods stored, sea vessels, as well as hinterland transportation vehicles and infrastructures. • Higher terminal downtime due to higher dredging requirement induced by silts and debris run-off to seawater. • Lower volume of goods served by the terminal due to slower marine traffic and higher downtimes of internal and landside operations.	√	√		All	ENV	• Offsite and water pollution due to dredging, especially if the dredged materials are not stored and recycled properly. • Lower water and air qualities due to run-offs of greywater, blackwater, dusts, silts and debris to waterways, as well as spills of stored goods. • Higher threat to species living within or around the terminal due to improper dredging, the run-offs and spills.		Gaythwaite (2004); van Pomeren (2014)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for dredging and cleaning all affected assets, additional maintenance requirements for the affected assets, replacement of the damaged assets, compensating the damaged goods and compensating the loss of the vegetations and species.		
												SOC	• Lower health quality and well-being, as well as death of terminal labours and residents living nearby the terminal due to eyes disease, high winds and working accidents induced by the storm. • Migration of residents or workers, whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water (e.g. fisherman).		
11	High fogginess and relative humidity	OPE	Navigation and Connection to hinterland connection	Sea vessels and waterways	Visibility level	Subjected to qualitative judgement by the marine traffic controller	• Reduction in the safety of marine traffic. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage or loss of sea vessels and goods being carried in the vessels in case of any marine traffic accident.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Author
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
12	High fogginess and relative humidity	OPE	Berthing and Connection to hinterland connection	Sea vessels and berthing assets	Visibility level	Subjected to qualitative judgment by the marine traffic controller	• Reduction in the berthability of the incoming vessels. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to berthing assets in case of any berthing accident. • Damage or loss of sea vessels and goods being carried in the vessels in case of any berthing accident. • Higher vegetation growth in the berthing area.	√	√		All	OPE	• Slower or inoperational navigation, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Author
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected berthing assets, sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems and removing the unwanted vegetation.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
13	High fogginess and relative humidity	OPE	Goods handling	Quay cranes	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of quay cranes. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of quay cranes and goods being handled in case of any goods handling accident.	√	√		All	OPE	• Slower or inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection of the terminal.		Author; van Pomeren (2014)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected quay cranes and goods.		
												SOC	• Injury and death of port labors in case of any severe goods handling accident.		

14	High fogginess and relative humidity		OPE	Ground transportation	Ground vehicles	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of ground vehicles. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of ground vehicles and goods being transported in case of any ground transportation accident.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Author; van Pomeren (2014)
													FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected ground vehicles and goods.		
													SOC	• Injury and death of port labors in case of any severe ground transportation accident.		
15	High fogginess and relative humidity		OPE	Goods storing	Goods storing equipment and goods storages	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of goods storing equipment. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of goods storing equipment, goods storages and goods being stored in case of any goods storing accident.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Author; van Pomeren (2014)
													FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
													SOC	• Injury and death of port labors in case of any severe goods storing accident.		
16	High fogginess and relative humidity		OPE	Connection to hinterland connection	Trucks and trains	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of connection to hinterland transporters. • Lower volume of goods served by the terminal due to slower or higher downtime of landside operation. • Damage or loss of trucks, trains, truck stations, train stations and goods being transported in case of any accident in goods transfer to hinterland transporters.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Author; van Pomeren (2014)
													FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations, as well as goods being transported.		
													SOC	• Injury and death of port labors in case of any accident in transferring goods to hinterland transporters.		
17	High precipitation, snowfall and hail, including those induced by storm		OPE	Navigation and Connection to hinterland connection	Sea vessels and waterways	Visibility level	Subjected to qualitative judgment by the marine traffic controller	• Reduction in the safety of marine traffic. • Reduction in the ship navigability as a result of higher sedimentation rate and amount of silts and debris run-off to waterways, leading to lower draft clearance or water depth. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage or loss of sea vessels and goods being carried in the vessels in case of any traffic accident or extreme rainfall, snowfall and hail.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Stenek et al. (2011), USTRB (2008)
													ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
													FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems.		
													SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
18	High precipitation, snowfall and hail, including those induced by storm		OPE	Berthing and Connection to hinterland connection	Sea vessels and berthing assets	Visibility level	Subjected to qualitative judgment by the marine traffic controller	• Reduction in the berthability of the incoming vessels. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to berthing assets in case of any berthing accident or extreme rainfall, snowfall and hail. • Damage or loss of sea vessels and goods being carried in the vessels in case of any berthing accident or extreme rainfall, snowfall and hail. • Higher vegetation growth in the berthing area.	√	√		All, in particular Goods Handling	OPE	• Slower or inoperational navigation, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Stenek et al. (2011), USTRB (2008)
													ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
													FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected berthing assets, sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems and removing the unwanted vegetation.		
													SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		

19	High precipitation, snowfall and hail, including those induced by storm	OPE	Goods handling	Quay cranes	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of quay cranes. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of quay cranes and goods being handled in case of any goods handling accident or extreme rainfall, snowfall and hail.	√	√		All	OPE	• Slower or inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011), van Pomeren (2014)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected quay cranes and goods.		
												SOC	• Injury and death of port labors in case of any severe goods handling accident. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
20	High precipitation, snowfall and hail, including those induced by storm	OPE	Ground transportation	Internal roads and ground vehicles	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Damage to internal roads due to erosion or increased soil moisture of the road, especially if the road is unpaved. • Reduction in the operationality of ground vehicles, especially if Automated Guided Vehicles are employed for ground transportation. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of ground vehicles and goods being transported in case of any ground transportation accident or extreme rainfall, snowfall and hail.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011), van Pomeren (2014)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected internal roads, ground vehicles and goods.		
												SOC	• Injury and death of port labors in case of any severe ground transportation accident. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
21	High precipitation, snowfall and hail, including those induced by storm	OPE	Goods storing	Goods storing equipment and goods storages	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Reduction in the operationality of goods storing equipment. • Inoperative goods storages, especially those exposed to rainfall, snowfall and hail. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of goods storing equipment, goods storages and goods being stored in case of any goods storing accident or extreme rainfall, snowfall and hail.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011), van Pomeren (2014)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
												SOC	• Injury and death of port labors in case of any severe goods storing accident. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
22	High precipitation, snowfall and hail, including those induced by storm	OPE	Connection to hinterland connection	Roads, railways, truck stations, train stations, trucks and trains	Visibility level	Subjected to qualitative judgment by the operators. In Rotterdam World Gateway terminal: < 200 m	• Damage in the soil stability of the roads and railways due to increasing soil moisture. • Reduction in the operationality of connection to hinterland transporters. • Lower volume of goods served by the terminal due to slower or higher downtime of landside operation. • Damage or loss of trucks, trains, truck stations, train stations and goods being transported in case of any accident in goods transfer to hinterland transporters.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Connell et al. (2015), DEFRA (2012), Scott et al. (2013), Stenek et al. (2011), van Pomeren (2014)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations, as well as goods being transported.		
												SOC	• Injury and death of port labors in case of any accident in transferring goods to hinterland transporters. • Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		

23	High precipitation, snowfall and hail, including those induced by storm	OPE	All	Power supply, internal communication network	Rainfall, snowfall, hail rate	Still unknown	• Inoperationality of radar and radio equipment if the internal communication network is disrupted. • Reduction in the safety level of terminal operations, in particular the navigation sub-operation. • Inoperationality of terminal operations if power supply is disrupted, especially those dependent on the supply. • Damage to stored goods that require cooling and heating. • Disruption in the whole terminal operations due to the inoperationality of terminal operators who are in charge of managing the incoming and outgoing sea vessels, as well as the flow of goods within the terminal.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected power stations, internal communication network, goods and other terminal assets.		
												SOC	• Injury and death of port labors in case of any severe accident induced by discontinuity of power supply and internal communication network.		
24	High precipitation, snowfall and hail, including those induced by storm	OPE	All	Drainage system	Precipitation	Dependent on the drainage capacity of the terminal	• Reduced drainage capacity due to clogging in drainage system. • Higher risk of ground flooding.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal in case of ground flooding.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal during ground flooding event. • Higher operational expenditure/insurance premium for additional maintenance requirements for the affected drainage system.		
												SOC	• Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced during ground flooding event. • Migration of residents or workers due to disease/virus breakout.		
25	High wave, including that induced by storm	OPE	Navigation and Connection to hinterland connection	Sea vessels, waterways and other navigation assets	Wave height	> 1.5 m	• Reduction in the safety of marine traffic. • Reduction in the ship navigability as a result of rougher and wilder waves. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage or loss of sea vessels and goods being carried in the vessels in case of any traffic accident or extreme waves. • Damage or loss of navigation assets (e.g. sea locks, navigation lights and buoys) in case of any traffic accident or extreme waves.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), de Jong (personal communication, 2016), Rossouw and Theron (2009), Scott et al. (2013), Stenek et al. (2011)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected sea vessels, navigation assets and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
26	High wave, including that induced by storm	OPE	Berthing and Connection to hinterland connection	Sea vessels and berthing assets	Wave height	Dependent on the existence of breakwater	• Reduction in the berthability of the incoming vessels. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to berthing assets in case of any berthing accident or extreme waves. • Damage or loss of sea vessels and goods being carried in the vessels in case of any berthing accident or extreme waves.	√	√		All, in particular Goods Handling	OPE	• Slower or inoperational navigation, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), Rossouw and Theron (2009)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected berthing assets, sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species and providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		

27	High wind, including that induced by storm	OPE	Navigation and Connection to hinterland connection	Sea vessels, waterways and other navigation assets	Wave height	> 17.5 m/s, according to Gaythwaite (2004), but subjected to the specifications of the vessels	• Reduction in the safety of marine traffic. • Reduction in the ship navigability as a result of rougher and wilder winds. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage or loss of sea vessels and goods being carried in the vessels in case of any traffic accident or extreme winds. • Damage or loss of navigation assets (e.g. sea locks, navigation lights and buoys) in case of any traffic accident or extreme winds.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), de Jong (personal communication, 2016), Rossouw and Theron (2009), Scott et al. (2013), Stenek et al. (2011)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected sea vessels, navigation assets and goods, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
28	High wind, including that induced by storm	OPE	Berthing and Connection to hinterland connection	Sea vessels and berthing assets	Wind speed	> 11.5 m/s, according to Gaythwaite (2004), but subjected to the specifications of the vessels and berthing facilities	• Reduction in the berthability of the incoming vessels. • Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to berthing assets in case of any berthing accident or extreme winds. • Damage or loss of sea vessels and goods being carried in the vessels in case of any berthing accident or extreme winds.	√	√		All, in particular Goods Handling	OPE	• Slower or inoperational navigation, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), Rossouw and Theron (2009)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected berthing assets, sea vessels and goods, more frequent dredging, compensating the loss of vegetation and species and providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		
29	High wind, including that induced by storm	OPE	Goods handling	Quay cranes	Wind speed	> 11.5 m/s (Inoperativeness)	• Reduction in the operationality of quay cranes. • Lower volume of goods served by the port due to slower internal operation/higher terminal downtime. • Damage/loss of quay cranes and goods being handled in case of any goods handling accident or extreme winds.	-	√		All	OPE	• Slower/inoperational navigation, berthing, ground transportation, goods storing and connection sub-operations of the terminal.		Connell et al. (2015), Gaythwaite (2004), Scott et al. (2013), Stenek et al. (2011)
						> 24.5 m/s (Damage to quay cranes if they are not lashed properly)		√	-			FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance requirements for the affected quay cranes and goods. • Higher operational expenditure/insurance premium for replacements of the damaged quay cranes and goods.		
						> 56 m/s (Damage to quay cranes even if they are lashed properly)		√	-			SOC	• Injury and death of port labors in case of any severe winds or goods handling accident.		
30	High wind, including that induced by storm	OPE	Ground transportation	Internal roads and ground vehicles	Wind speed	> 24.5 m/s according to Gaythwaite (2004) > 28.5 m/s in Rotterdam World Gateway terminal , but subjected to the specification of the vehicles	• Damage to internal roads, especially if the road is unpaved. • Reduction in the operationality of ground vehicles. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of ground vehicles and goods being transported in case of any ground transportation accident.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Gaythwaite (2004), van Pomeren (2014)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected internal roads, ground vehicles and goods.		
												SOC	• Injury and death of port labors in case of any severe ground transportation accident.		
31	High wind, including that induced by storm	OPE	Goods storing	Goods storing equipment and goods storages	Wind speed	> 11.5 m/s according to Gaythwaite (2004) > 22 m/s in Rotterdam World Gateway terminal , but subjected to the specification of the goods storing equipment	• Reduction in the operationality of goods storing equipment. • Inoperativeness of goods storages, especially those exposed to winds. • Lower volume of goods served by the terminal due to reduction in the terminal storing capacity, as well as slower or higher downtime of internal operation. • Damage or loss of goods storing equipment, goods storages and goods being stored in case of any goods storing accident (e.g. collapse of stack formation).	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Gaythwaite (2004), van Pomeren (2014)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
												SOC	• Injury and death of port labors in case of any severe goods storing accident.		

32	High wind, including that induced by storm	OPE	Connection to hinterland connection	Roads, railways, truck stations, train stations, trucks and trains	Wind speed	> 11.5 m/s according to Gaythwaite (2004) > 22 m/s in Rotterdam World Gateway terminal , but subjected to the specification of the goods storing equipment	• Damage to the supporting structures for roads and railways, such as highway bridge decks. • Reduction in the operationality of connection to hinterland transporters as high sided vehicles become increasingly unstable during high winds and debris can be left on roads during such events. • Lower volume of goods served by the terminal due to slower or higher downtime of landside operation. • Damage or loss of trucks, trains, truck stations, train stations and goods being transported in case of any accident in goods transfer to hinterland transporters.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Author; van Pomeren (2014)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations, as well as goods being transported.		
												SOC	• Injury and death of port labors in case of any accident in transferring goods to hinterland transporters.		
33	High wind, including that induced by storm	OPE	All	Power supply, internal communication network and marine traffic service tower	Wind speed	Still unknown	• Inoperationality of radar and radio equipment if the internal communication network is disrupted. • Reduction in the safety level of terminal operations, in particular the navigation sub-operation. • Inoperationality of terminal operations if power supply is disrupted, especially those dependent on the supply. • Damage to stored goods that require cooling and heating. • Disruption in the whole terminal operations due to the inoperationality of terminal operators who are in charge of managing the incoming and outgoing sea vessels, as well as the flow of goods within the terminal. • Damage to marine traffic service towers.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected power stations, internal communication network, marine traffic service towers, goods and other terminal assets.		
												SOC	• Injury and death of port labors in case of any severe accident induced by discontinuity of power supply and internal communication network.		
34	Lightning	OPE	Goods handling	Quay cranes	Lightning strength	Still unknown	• Reduction in the operationality of quay cranes. • Lower volume of goods served by the port due to slower internal operation/higher terminal downtime. • Damage/loss of quay cranes and goods being handled in case of any goods handling accident or extreme winds.	√	√		All	OPE	• Slower/inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Chhetri et al. (2013)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance requirements for the affected quay cranes and goods. • Higher operational expenditure/insurance premium for replacements of the damaged quay cranes and goods.		
												SOC	• Injury and death of port labors in case of any severe lightning or goods handling accident.		
35	Lightning	OPE	Ground transportation	Ground vehicles	Lightning strength	Still unknown	• Reduction in the operationality of ground vehicles. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of ground vehicles and goods being transported in case of any ground transportation accident.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Chhetri et al. (2013)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected ground vehicles and goods.		
												SOC	• Injury and death of port labors in case of any severe lightning and ground transportation accident.		
36	Lightning	OPE	Goods storing	Goods storing equipment and goods storages	Lightning strength	Still unknown	• Reduction in the operationality of goods storing equipment, especially those that possess electrical systems. • Inoperativeness of goods storages, especially those exposed to the direct impacts of lightning. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of goods storing equipment, goods storages and goods being stored in case of any goods storing accident. • Fire in goods storages could be induced by burned commodities that are not resistant to electricity.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Chhetri et al. (2013)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
												SOC	• Injury and death of port labors in case of any severe lightning and goods storing accident.		
37	Lightning	OPE	Connection to hinterland connection	Roads, railways, truck stations, train stations, trucks and trains	Lightning strength	Still unknown	• Reduction in the operationality of hinterland transportation modes that are dependent on electrical system (e.g. electric trains). • Lower volume of goods served by the terminal due to slower or higher downtime of landside operation. • Damage or loss of trucks, trains, truck stations, train stations and goods being transported in case of any accident in goods transfer to hinterland transporters.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations, as well as goods being transported.		
												SOC	• Injury and death of port labors in case of any accident in transferring goods to hinterland transporters.		
38	Lightning	OPE	All	Power supply, internal communication network	Lightning strength	Still unknown	• Inoperationality of radar and radio equipment if the internal communication network is disrupted. • Reduction in the safety level of terminal operations, in particular the navigation sub-operation. • Inoperationality of terminal operations if power supply is disrupted, especially those dependent on the supply. • Damage to stored goods that require cooling and heating. • Disruption in the whole terminal operations due to the inoperationality of terminal operators who are in charge of managing the incoming and outgoing sea vessels, as well as the flow of goods within the terminal.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected power stations, internal communication network, goods and other terminal assets.		
												SOC	• Injury and death of port labors in case of any severe accident induced by discontinuity of power supply and internal communication network.		

39	High air/sea temperature	FIN	All	Waterways	ΔNumber of days of ice-free waterways	> 0 day/year	• Increase in the length of shipping season for terminals situated in high-latitude zone. • Shorter shipping distance and less fuel consumption for shipping due to opening up of new transportation routes in high-latitude zone. • Reduction in maintenance costs of waterways of terminals situated in high-latitude zone, due to the reduction in volume of ices that should be removed from the waterways. • Threats to terminals situated in mid- and low-latitude zones as the competition among terminals will be elevated.		√		None	None	None		Stenek et al. (2011)
40	Low air/sea temperature	FIN	All	Waterways	ΔNumber of days of ice-free waterways	< 0 day/year	• Reduction in the length of shipping season for terminals situated in high-latitude zone. • Longer shipping distance and more fuel consumption for shipping due to opening up of new transportation routes in high-latitude zone. • Increase in maintenance costs of waterways of terminals situated in high-latitude zone, due to the reduction in volume of ices that should be removed from the waterways. • Opportunities to terminals situated in mid- and low-latitude zones as the competition among terminals will be elevated.		√		None	None	None		Stenek et al. (2011)
41	High [low] air/sea temperature	OPE	Navigation and Connection to hinterland connection	Sea vessels, waterways and other navigation assets	Air temperature Sea surface temperature	> 42°C [< 0°C] Still unknown [< 7°C]	• Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to navigation assets (e.g. sea locks, navigation lights and buoys) and sea vessels due to reduction in their structural integrities.	√	√		All	OPE	• Slower or inoperational berthing, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), Overland (1989), Ports and Ships Maritime News (2007), Stenek et al. (2011), USEPA (2008)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected sea vessels, navigation assets, more frequent dredging, compensating the loss of vegetation and species, providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water. • Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
42	High [low] air/sea temperature	OPE	Berthing and Connection to hinterland connection	Sea vessels and berthing assets	Air temperature Sea surface temperature	> 42°C [< 0°C] Still unknown [< 7°C]	• Lower volume of goods served by the terminal due to slower marine traffic or higher terminal downtime. • Damage to berthing assets and sea vessels due to reduction in their structural integrities.	√	√		All	OPE	• Slower or inoperational navigation, goods handling, ground transportation, goods storing and connection to hinterland connection of the terminal. • Higher requirement for support systems (e.g. search and rescue supports).		Connell et al. (2015), Overland (1989), Stenek et al. (2011)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance and replacement requirements for the affected berthing assets, sea vessels, more frequent dredging, compensating the loss of vegetation and species and providing additional support systems.		
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water. • Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		

43	High [low] air/sea temperature	OPE	Goods handling	Quay cranes	Air temperature	> 42°C [Still unknown]	• Damage to quay cranes due to buckling, reduction in their structural integrities and increasing corrosion [icing or freezing] rate. • Lower volume of goods served by the port due to inoperative cranes.	√	√		All	OPE	• Slower/inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance requirements for the affected quay cranes. • Higher operational expenditure/insurance premium for replacements of the damaged quay cranes.		
												SOC	• Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
44	High [low] air/sea temperature	OPE	Ground transportation	Internal roads and ground vehicles	Air temperature	> 42°C [Still unknown]	• Damage to internal roads and ground vehicles due to buckling, reduction in their structural integrities and increasing corrosion [icing or freezing] rate. • Lower volume of goods served by the port due to inoperative internal roads and ground vehicles.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected internal roads and ground vehicles.		
												SOC	• Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
45	High [low] air/sea temperature	OPE	Goods storing	Goods storing equipment and goods storages	ΔAir temperature	> 0°C [<0°C]	• Damage to goods storing equipment and goods storages due to buckling, reduction in their structural integrities and increasing corrosion [icing or freezing] rate. • Lower volume of goods served by the terminal due to inoperative equipment and storages. • Higher energy demand for cooling [heating] purpose. • Damage to the stored goods if they are not adequately cooled [heated]. • Fire in goods storages and dust explosion as a result of burned commodities that are not resistant to high temperatures.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												ENV	• Lower air quality due to fire and dust explosion. • Higher carbon emission due to higher cooling [heating] energy demand.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
												SOC	• Injury and death of port labors in case of any severe fire and dust explosion. • Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
46	High [low] air/sea temperature	OPE	Connection to hinterland connection	Roads, railways, truck stations, train stations, trucks and trains	Air temperature	> 42°C [Still unknown]	• Damage to hinterland transportation modes, railways and roads due to wear, tear, buckling, reduction in their structural integrities and increasing corrosion [icing or freezing] rate. • Reduction in the allowable speed of trains and trucks, leading to delay or slower goods transportation. • Lower volume of goods served by the terminal due to slower hinterland traffic or higher terminal downtime.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Connell et al. (2015), Dft (2004), Stenek et al. (2011)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations.		
												SOC	• Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
47	High [low] air/sea temperature	OPE	All	Power supply and internal communication network	Air temperature	Still unknown	• Inoperationality of radar and radio equipment if the internal communication network is disrupted. • Reduction in the safety level of terminal operations, in particular the navigation sub-operation. • Inoperationality of terminal operations if power supply is disrupted, especially those dependent on the supply. • Damage to stored goods that require cooling and heating. • Disruption in the whole terminal operations due to the inoperationality of terminal operators who are in charge of managing the incoming and outgoing sea vessels, as well as the flow of goods within the terminal.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Author
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected power stations, internal communication network, goods and other terminal assets.		
												SOC	• Injury and death of port labors in case of any severe accident induced by discontinuity of power supply and internal communication network. • Reduction in health or death of terminal labours due to heat [cold] waves and dehydration [excessive cold].		
48	Average sea level rise	OPE	Navigation and Connection to hinterland connection	Waterways	ΔWater level	> 0 cm	• Enhancement in the safety of marine traffic and size of sea vessels accommodable. • Increase in the ship navigability as a result of greater water depth or draft clearance. • Higher volume of goods served by the terminal due to faster marine traffic or lower terminal downtime,.		√		All	OPE	• Higher operational time for berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Stenek et al. (2011)
												ENV	• Enhanced environmental performance of the terminal as the amount of pollutants from dredging is reduced.		
												FIN	• Increase in terminal profit due to lower port downtime and higher volume of goods served by the terminal. • Lower operational expenditure/insurance premium for dredging as the dredging requirement is reduced.		
49	Average sea level rise	OPE	Navigation and Connection to hinterland connection	Waterways	ΔWater level	< 0 cm	• Lower bridge clearance, leading to smaller size of sea vessels accommodable and hence lower volume of goods served by the port.		√		All	FIN	• Lower terminal profit due to lower volume of goods served by the terminal.		Stenek et al. (2011)

50	Seawater/ Ground/River flooding, including that induced by storm	OPE	Goods handling	Quay cranes	Water level	> Topography level of quays	• Disruption in the operationality of quay cranes. • Lower volume of goods served by the port due to inoperational quay cranes. • Damage/loss of quay cranes and goods being handled in case of any goods handling accident or extreme flooding.	√	√		All	OPE	• Slower/inoperational navigation, berthing, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected quay cranes and goods.		
												SOC	• Injury and death of port labors in case of any severe flooding or goods handling accident. • Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers due to disease/virus breakout.		
51	Seawater/ Ground/River flooding, including that induced by storm	OPE	Ground transportation	Internal roads and ground vehicles	Water level	> Topography level of internal roads	• Damage to internal roads due to erosion or increased soil moisture of the road, especially if the road is unpaved. • Reduction in the operationality of ground vehicles or disoperation of ground transportation if the internal roads are flooded. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of ground vehicles and goods being transported in case of any ground transportation accident or extreme flooding.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, goods storing and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected ground vehicles and goods.		
												SOC	• Injury and death of port labors in case of any severe flooding or ground transportation accident. • Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers due to disease/virus breakout.		
52	Seawater/ Ground/River flooding, including that induced by storm	OPE	Goods storing	Goods storing equipment and goods storages	Water level	> Topography level of goods storages	• Reduction in the operationality of goods storing equipment, especially those that possess electrical systems. • Inoperativeness of goods storages, especially those vulnerable to flooding. • Lower volume of goods served by the terminal due to slower or higher downtime of internal operation. • Damage or loss of goods storing equipment, goods storages and goods being stored in case of any goods storing accident or extreme flooding.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and connection to hinterland connection of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected goods storing equipment, goods storages and goods being stored.		
												SOC	• Injury and death of port labors in case of any severe flooding or goods storing accident. • Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers due to disease/virus breakout.		

53	Seawater/ Ground/River flooding, including that induced by storm	OPE	Connection to hinterland connection	Roads, railways, truck stations, train stations, trucks and trains	Water level	> Topography level of truck and train stations	• Damage to soil stability of the roads and railways due to increasing soil moisture. • Reduction in the operationality of hinterland transportation modes that are dependent on electrical system (e.g. electric trains). • Lower volume of goods served by the terminal due to slower or higher downtime of landside operation. • Damage or loss of trucks, trains, truck stations, train stations and goods being transported in case of any accident in goods transfer to hinterland transporters.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation and goods storing of the terminal.		Connell et al. (2015), Stenek et al. (2011), USGCRP (2009)
												ENV	• Water pollution due to run-offs of debris and goods into waterways. • Off-site and water pollutions due to unwanted vegetation growth and dredging, especially if the dredged materials are not stored and recycled properly. • Higher threat to species living within or around the terminal due to improper dredging and the run-offs.		
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected hinterland transportation vehicles and stations, as well as goods being transferred to hinterland transporters.		
												SOC	• Injury and death of port labors in case of any severe flooding or accident in transferring the goods to hinterland transporters. • Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers due to disease/virus breakout.		
54	Seawater/ Ground/River flooding, including that induced by storm	OPE	All	Power supply, internal communication network and marine traffic service tower	Water level	> Topography level of power station, internal communication network and marine traffic service tower	• Inoperationality of radar and radio equipment if the internal communication network is disrupted. • Reduction in the safety level of terminal operations, in particular the navigation sub-operation. • Inoperationality of terminal operations if power supply is disrupted, especially those dependent on the supply. • Damage to stored goods that require cooling and heating. • Disruption in the whole terminal operations due to the inoperationality of terminal operators who are in charge of managing the incoming and outgoing sea vessels, as well as the flow of goods within the terminal.	√	√		All	OPE	• Slower or inoperational navigation, berthing, goods handling, ground transportation, goods storing and connection to hinterland connection sub-operations of the terminal.		Connell et al. (2015), Stenek et al. (2011)
												FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected power stations, internal communication network, marine traffic service towers, goods and other terminal assets.		
												SOC	• Injury and death of port labors in case of any severe flooding or accident in transferring the goods to hinterland transporters. • Lower health quality and death of terminal labors and residents living nearby the terminal due to increase in the amount of disease/virus carrying transmittances (e.g. dengue carrying mosquitos), whose habilitabilities are enhanced in drought season. • Migration of residents or workers due to disease/virus breakout.		
55	High salinity of seawater, high air humidity, high CO_2 concentration in air and seawater	OPE	Navigation, Berthing and Connection to hinterland connection	Sea vessels, navigation and berthing assets	pH of seawater, Relative humidity, CO_2 concentration	$\Delta pH < 0$, Δrelative humidity > 0, ΔCO_2 concentration > 0	• Lower volume of goods served by the port due to slower traffic. • Damage to sea vessels in a long-term due to reduction in their structural integrities and increasing corrosion rate. • Damage to navigation and berthing assets in case of reduction in their structural integrities and increasing corrosion rate.	√	√		All	FIN	• Lower terminal profit due to lower volume of goods served by the terminal. • Higher operational expenditure/insurance premium for additional maintenance or replacement requirements for the affected terminal assets.		Stenek et al. (2011)
												SOC	• Migration of residents or workers whose main incomes are dependent on the functionality of the terminal and quality of the surrounding water.		

***OPE = Operational; FIN = Financial; ENV = Environmental; SOC = Social**

Magnitude	Description	Impact
N/A	No risk/opportunity or the risk/opportunity type is irrelevant	
Opp	Opportunity	Operational: Lower annual terminal downtime Financial: Increase in net annual operational cash flow Environmental: Enhancement in the habitability of vegetations, birds, species, as well as increase in air and water qualities Social: Positive impact on port labors and society
L	Low risk	Operational: < 1% increase in annual terminal downtime Financial: < 1% reduction in net annual operational cash flow Environmental: Minor and reversible impacts on vegetations, birds, species, air and water qualities Social: Minor and tolerable impact on port labors and society
M	Medium risk	Operational: 1% - 10% increase in annual terminal downtime Financial: 1% - 5% reduction in net annual operational cash flow Environmental: Medium and irreversible, but temporary impacts on vegetations, birds, species, air and water qualities Social: Medium, temporary and tolerable impact on port labors and society
H	High risk	Operational: > 10% increase in annual terminal downtime Financial: > 5% reduction in net annual operational cash flow Environmental: Major, irreversible and long-term impacts on vegetations, birds, species, air and water qualities Social: Major, long term and intolerable impact on port labors and society

Appendix D - Additional Information for TMMeB Case Study

In this appendix, additional information regarding the financial analysis in TMMeB is presented. It includes (1) the approximation of the financial impact of causeway flooding on *annual revenue of TMMeB operations* from 2016 to 2032, (2) a normal probability plot of the normalized historical data of hourly sea levels in TMMeB and (3) the estimation of the range of possible future sea levels in TMMeB from 2016 to 2032.

D.1 Financial Impacts of Causeway Flooding in TMMeB

Stenek et al. (2011, p. 37) have projected the *annual revenues of TMMeB* from different commodities, which are container, bulk cargo, grain and coke. The projection indicates that the *annual revenue of TMMeB* from its containers-related operations in 2015 is USD 24,925,780 and it is expected to grow with an annual growth rate of 3% from 2015 to 2037. Based on these two information, the *annual revenue of TMMeB* from 2016 to 2032 (i.e. the selected assessment time frame) from handling and storing containers can be estimated. Moreover, as described in Chapter 6.1, by assuming that (1) the terminal is operated for 24 hours every day and (2) the flow of containers through TMMeB is uniform throughout a day, the loss of *annual revenue of TMMeB* per hour in any year within the assessment time frame because of causeway flooding can be approximated, as shown in Table D-1.

Table D-1: Approximation of the cost of causeway flooding for TMMeB case study

Year	Expected annual revenue of TMMeB from containers-related operations (2010 USD)	Estimated loss of annual revenue of TMMeB from containers-related operations because of causeway flooding (2010 USD)
2015	24,925,780	-
2016	24,925,780 * 1.03 = 25,673,550	25,673,550/365/24 = 2,931/hour
2017	25,673,550 * 1.03 = 26,443,760	26,443,760/365/24 = 3,019/hour
2018	26,443,760 * 1.03 = 27,237,070	27,237,070/365/24 = 3,109/hour
2019	28,054,185	3,203/hour
2020	28,895,810	3,299/hour
2021	29,762,685	3,398/hour
2022	30,655,565	3,499/hour
2023	31,575,230	3,604/hour
2024	32,522,490	3,713/hour
2025	33,498,165	3,824/hour
2026	34,503,105	3,939/hour
2027	35,538,200	4,057/hour
2028	36,604,345	4,179/hour
2029	37,702,475	4,304/hour
2030	38,833,550	4,433/hour
2031	39,998,560	4,566/hour
2032	41,198,515	4,703/hour

D.2 Normal Probability Plot of Historical Sea Levels in TMMeB

A visual inspection on the normal probability plot of the normalized historical sea level data in TMMeB for the periods of 1951 – 2002 and 2006 – 2014 is presented in Figure D-1. It shows that the data fits normal distribution well as the observed cumulative probability is about on the same line as the expected cumulative probability. It should be noted that all non-parametric tests that are commonly used for checking the normality of a distribution, such as Kolmogorov-Smirnov test, could lead to misleading outcome as the sample size in the dataset is a way too large, which is 457,047. Therefore, visual inspection fits best for assessing the normality of the normalized sea levels in TMMeB.

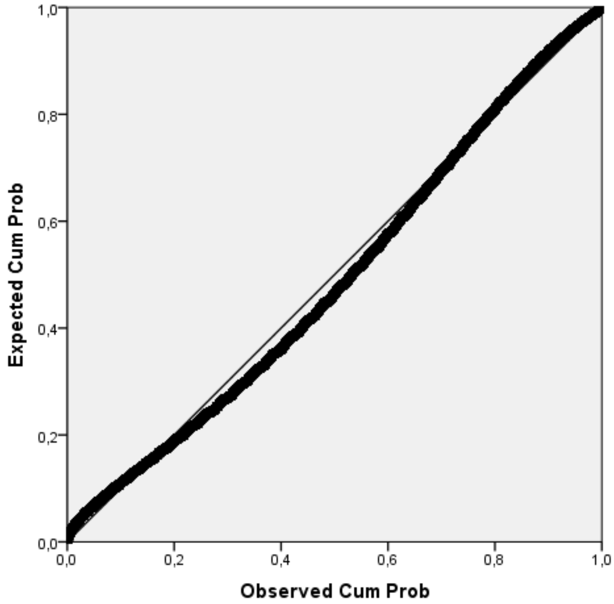


Figure D-1: Normal probability plot of the normalized sea levels in TMMeB from 1951 to 2014

D.3 Projecting Future Sea Level in TMMeB

The sea level projections of the Intergovernmental Panel on Climate Change (IPCC) presented in Church et al. (2014, p. 1181) were employed to estimate the potential range of sea levels in TMMeB between 2016 and 2032. Obviously, such exercise was performed based on an assumption that the average sea level trend in TMMeB resembles the trend of the global mean sea level well. From Figure D-2, it appears that the minimum sea level rise scenario is the lower bound of the presented RCP 2.6 scenarios, in which the average sea level in 2100 is expected to be 28cm higher than the average level in 2000. The chart also suggests that the trend for the minimum-bound scenario is linearly increasing. Moreover, based on Figure D-2, the maximum sea level rise scenario refers to the upper bound of the presented RCP 8.5 scenarios, in which the average sea level in 2100 is expected to be 100cm higher than the average level in 2000. Further, the chart shows that the trend for the maximum-bound scenario is exponentially rising.

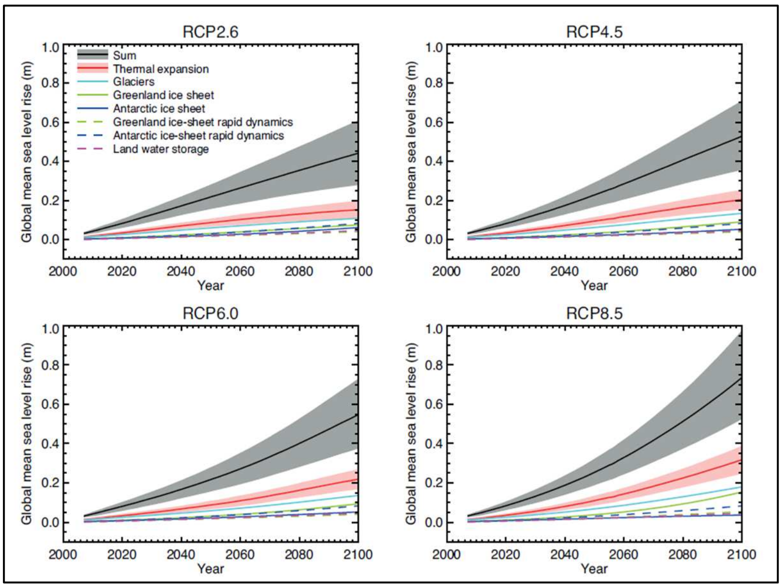


Figure D-2: Projections of global average annual sea level from 2000 to 2100 by IPCC. Source: Church et al. (2014, p. 1181)

Based on the identified values and trends, the minimum and maximum average annual sea levels in TMMeB in the future could be estimated, as shown in Table D-2 and Table D-3, respectively. Firstly, the lowest possible average sea level rise scenario for TMMeB was projected by treating the trend as a linearly increasing one. From the database of University of Hawaii Sea Level Center (2016), the average sea level in TMMeB in 2015 was expected to be 912mm. By projecting the level to 2032 linearly, the lower bound of average sea level in TMMeB in 2032 can be estimated.

Table D-2: Projection of the lowest scenario of future sea level rise in TMMeB from 2015 to 2032

Year	**2000**	**2015**	**2032**	**2100**
Average annual sea level (IPCC) – Baseline: 2000 (mm)	0	42	90	280
Average annual sea level (IPCC) – Baseline: 2015 (mm)	-	0	48	238
Projected average annual sea level in TMMeB (mm)	-	912	**960**	1,150

Secondly, the maximum possible sea level rise scenario for TMMeB was extrapolated by treating the trend as an exponentially rising one. Similarly, by projecting the level in 2015 (i.e. 912mm) to 2032 exponentially, the upper bound of average sea level in TMMeB in 2032 can be approximated.

Table D-3: Projection of the highest scenario of future sea level rise in TMMeB from 2015 to 2032

Year	**2000**	**2015**	**2032**	**2100**
Average annual sea level (IPCC) – Baseline: 2000 (mm)	0	70	180	1,000
Average annual sea level (IPCC) – Baseline: 2015 (mm)	-	0	110	930
Projected average annual sea level in TMMeB (mm)	-	912	**1,022**	1,842

Based on the extrapolations, which are described in Table D-2 and Table D-3, the average sea level in TMMeB in 2032 is expected to be within the range of 960mm – 1,022mm.

Appendix E - Summary of Interviews

In this appendix, summaries of interviews conducted in the research are provided. They are classified into three groups of (1) Interview set 1 (i.e. interviews for extracting additional information required for conducting the case study on TMMeB), (2) Interview set 2 (i.e. interview for extracting information about climate risks and responsibilities allocation agreement in Maasvlakte II) and (3) Interview set 3 (i.e. interview for validating the analysis of success factors of the Port of Rotterdam Authority for allocating climate risks and responsibilities in Maasvlakte II).

E.1 Interview Set 1

To support the case study on TMMeB, two interviews were executed during the research. Two respondents were approached and interviewed by e-mail; they are (1) Mr. Vladimir Stenek, the project manager of climate risks assessment for TMMeB and (2) Mr. Alan Duque Perez, the port manager of TMMeB. In this section, the questions mailed to them and their responses are presented.

E.1.1 Questions Sent to Mr. Vladimir Stenek

From: Erwanda Nugroho
Sent: Thursday, May 12, 2016 4:03 AM
To: Vladimir Stenek
Subject: Questions about Climate Risk Management in MEB

Dear Mr. Stenek,

Thank you very much for the informative presentation that you delivered yesterday. I am an MSc student at Delft University of Technology and I am currently conducting my thesis at Deltares on a subject of Financing Climate Risk Management in Ports.

So far, I have developed a climate risk assessment tool for ports, in particular container terminals. Moreover, I have developed a framework for (1) assessing the financial viabilities of the proposed climate adaptation measures for ports and (2) determining the optimum adaptation level for ports. Further, I have applied my framework on MEB.

I would like to extend my study to analyze how the costs of climate adaptation in ports can be shared between port stakeholders appropriately. Therefore, I have a few questions regarding your presentation yesterday, which are:

1. Were the adaptation measures implemented in MEB solely financed by the public sector? Or, in the other words, did the terminal operating company (i.e. Compas S.A.) participate in the financing as well?

2. In the report published by IFC, I recognized that insurances have been undertaken for several assets that are essential for the operations of MEB and Compas S.A., such as quays, goods handling equipment and goods stored in the terminal. Who was in charge of paying the insurance premiums in this case?

3. Is the reported annual discount rate of 16% a real or nominal discount rate?

4. How does the terminal deal with climate risks that are not avoidable, such as high wind speed, which could significantly disrupt the goods handling process and might destroy some assets?

Thank you very much for your time and attention in advance. I am looking forward to hearing from you and I am wishing you a very speedy recovery.

Yours sincerely,

Erwanda Nugroho

E.1.2 Responses from Mr. Vladimir Stenek

Dear Erwanda,

On 1, MEB –a private company- financed it with a purely private investment. In relation to insurance, policies for most of the assets were covered by MEB.

The discount rate is the one used by the company at that time. In general, those are derived from WACC, which is specific to each company and their financial structure.

Currently wind speed doesn't present significant problems for operations. In general, if lower than significant storm or higher speeds, the effect is mostly on berthing (depending on the berth orientation related to winds and effects on wave physics), and goods handling as related to crane operations.

The responses usually take a cost/benefit approach; if the frequency is relatively low in the first case the ships may need to temporarily leave berths causing some business disruption; if the effects start becoming significant hard measures such as changes in breakwaters may be needed. For cranes, the usual procedure is lashing above certain wind speed; in cases of older cranes with lower operational limit thresholds the response may be upgrading to newer standards with higher threshold tolerance. Operational procedures, such as stacking containers to lower heights when storms are announced, help prevent further damage. Responses may start differing for cyclones but luckily MEB is not in the zone of their activity.

Hope this helps.

Regards,

Vladimir

E.1.3 Questions Delivered to Mr. Alan Duque Perez

From: Erwanda Nugroho
Sent: Thursday, May 12, 2016 10:59 AM
To: Alan Duque Perez
Subject: RE: Exploring Possibility to Interview COMPAS S.A. for an MSc Thesis Project on Financing Climate Risk Management in Ports

Dear Mr. Perez,

Thank you for your quick reply and willingness to be interviewed. My questions are as follows:

1. Did COMPAS S.A. consider the climate risks faced by Muelles el Bosque Terminal before investing in the terminal operations?

2. Has COMPAS S.A. experienced any disruption in terminal operations or damage in terminal assets because of climate change impacts? What are the strategies or measures performed by COMPAS S.A. to mitigate such impacts in the future, if any?

3. How does COMPAS S.A. deal with climate risks that are not avoidable, such as high wind speed, which could significantly disrupt the goods handling process and might destroy some assets?

4. Does COMPAS S.A. insure their assets (e.g. goods handling equipment) and goods stored in the terminal? In case of any damage in the goods stored as a result of climate change impacts, who are responsible for compensating the owners of the goods?

5. According to the report published by the International Finance Corporation, some adaptation measures have been implemented in Muelles el Bosque Terminal. One of the examples is raising the causeway connecting the island and mainland areas. Did COMPAS S.A. participate in executing and/or financing the measures? Or, is it the responsibility of the other stakeholder(s)?

Thank you very much for your time and attention in advance. I am looking forward to hearing from you.

Kind regards,

Erwanda Nugroho

E.1.4 Summary of Responses from Mr. Alan Duque Perez

1. COMPAS S.A. did not consider any climate risk faced by Muelles el Bosque Terminal before investing in the terminal operations.

2. No damage has been observed since the infrastructures were raised by 1.5m.

3. COMPAS S.A. has identified the dates of strong wind events and set the maximum stacked formation of containers in yard to be 5 levels during those events.

4. Warehouses and cargo storages are used to protect the goods stored. In case of any accident, the damages are covered by insurance.

5. COMPAS S.A. was the only stakeholder that financed the climate adaptation investment in TMMeB.

E.2 Interview Set 2

Prof. Tiedo Vellinga, the Director of Environmental Monitoring for Maasvlakte II was approached and interviewed for the purpose of extracting information about climate risks and responsibilities allocation agreement in Maasvlakte II. In this section, the interview protocol and summary of his responses are presented.

E.2.1 Interview Protocol

Interview Protocol	
Author	Erwanda Nugroho
Respondent	Prof. Tiedo Vellinga (The Port of Rotterdam Authority)
Date of Interview	2 May 2016
Project Title	Financing Climate Risk Management in Ports

General Instructions

Good morning. Thank you for your time and availability for this interview. Currently, I am conducting a MSc thesis at Deltares on a topic of financing climate risk management in ports. As of today, I have developed a draft of climate risk assessment tool for ports and an assessment framework for analyzing the financial viabilities of the proposed climate adaptation measures for ports and the financially optimum climate adaptation level for ports. After acknowledging the viability and optimum adaptation level, the measures themselves have to be financed. Otherwise, the risk assessment and analysis would be meaningless. Therefore, the purpose of this interview is to acknowledge the drivers and current states of the Port of Rotterdam, in particular Maasvlakte II development and operations, in adapting to climate change and how the adaptation costs are arranged.

Instructions for Recording Permission

Before I start the interview, I would like to ask your permission for recording this interview. The purpose for recording our conversation is to ensure that I can get all of the details of your responses while having an attentive conversation with you at the same time. I assure you that the recording will remain confidential and only be used for the purpose of my research.

Questions: The drivers and current states of the Port of Rotterdam in adapting to climate change

1) The City and Port of Rotterdam have gained the reputation as one of the most climate adaptive cities and ports across the globe. From your point of view, what are the key drivers or success factors for the Port of Rotterdam to adapt to the climate change?

   Possible follow-up questions [If the interviewee feels that the question is too broad]:
   a) The safety regulation in the Netherlands could be one of the strictest in the world as all risks that occur once every 1,000 or 10,000 years have to be mitigated. Does the regulatory driver play an important role?
   b) The Port of Rotterdam is of great importance of the economies of the Netherlands and the neighbouring countries. Does the economic driver play an important role?
   c) As one of the biggest and leading ports in the world, the Port of Rotterdam has to maintain its competitiveness. Does the market driver play an important role?
   d) Many Dutch citizens are living nearby the Port of Rotterdam. Therefore, mitigating climate risks in the Port could also be beneficial for social purposes. Does the social driver play an important role?

2) How does the Port of Rotterdam conduct its climate risk assessment? How regularly is the assessment conducted?

3) The negative impacts of some climate risks, such as the disruption in cranes operation or damage in the cranes as a result of high wind speed, could be unmitigable or unavoidable. How does the Port of Rotterdam manage those unavoidable risks?

4) Insuring port assets and revenues is perhaps one of the most important climate risk management strategies in ports. In the Port of Rotterdam, what factors are taken into account when making decision between adapting, insuring and a combination of both?

Questions: The benefits and responsibilities of stakeholders of the Port of Rotterdam

5) Which stakeholders of the Port of Rotterdam gain benefits from the adaptation to climate change?

6) Which stakeholders of the Port of Rotterdam are responsible for implementing the relevant climate change adaptation measures? Are they responsible for financing the measures as well?

   Possible follow-up question:
   In one article, I found out that in the Port of Rotterdam, the Port Authority is responsible of developing seawalls while private operators are in charge of developing quays and some other port sites. Therefore, is it true that the measure of developing seawall should be executed by the Port Authority, while any measure to be implemented in quays and port sites (e.g. raising the height of quays) should be done by private operators?

7) Do the responsible stakeholders execute the measures by themselves? Or, are the executions tendered to external parties through public-private partnership, for instance?

8) How are the costs of climate adaptation shared among the stakeholders of the Port of Rotterdam?

   Possible follow-up question:
   If actor X (e.g. the Port Authority) is in charge of financing the measures, will the actor increase the fees imposed to the other stakeholders (e.g. port operators) or clients (e.g. frequently incoming sea vessels)?

9) From your perspective, what criteria or factors should be considered when making decisions on the adaptation cost sharing?

   Possible follow-up questions:
   a) [If the variations in costs of capital and discount rates among port stakeholders are not stated]: Different port stakeholders may have different weighted average cost of capital, or discount rate. Should this factor also be taken into account? For instance, stakeholders with the lowest cost of capital could be asked to finance the measures.
   b) [If fairness is mentioned as one of the criteria]: From my perspective, fairness in cost sharing can be defined into two different mechanisms: (1) All stakeholders will experience similar benefit-to-cost ratio, (2) The stakeholder(s) with the lowest cost of capital is paying for the adaptation costs. Which of the mechanism, if any, is relevant in Port of Rotterdam?

Closing Remarks

This is the end of my interview. Thank you very much for your time and responses. I find them very useful for my research project. I assure you that your personal details will not be published without seeking your approval beforehand. I hope to keep in touch with you through email and I will get back to you at the end of my research in order to validate my findings. At last, I would like to ask you to please introduce me to other relevant persons that might be interesting to be interviewed for my project.

[If time permits]: Do you have any question about my research project?

E.2.2 Summary of Responses

- The key driver is the aim of the City of Rotterdam to be the front-runner in innovative thinking with regard to climate adaptation strategies. The aim is indeed one of the goals of the business development of the City.

- The other drivers are also important, such as regulatory drivers, in which risks that occur once every 10,000 years have to be mitigated in the Netherlands. Moreover, the Port of Rotterdam has to maintain its competitiveness for attracting clients. Otherwise, the port can lose its competitiveness and the existing clients can shift its business to other ports. Further, there is a current perception that implementing climate adaptation measures in the Port of Rotterdam (e.g. building sea walls and storm surge barriers) helps in protecting Dutch residents from flooding. However, it turns out that there is not a lot of residents living nearby the port.

- The climate risk assessment is conducted by the Port of Rotterdam Authority and the City of Rotterdam. The cost, which is not so much compared to the execution of the measures, is borne mainly by the Port of Rotterdam Authority.

- The Rotterdam Climate Proof is a report that summarizes the climate risk assessment. It shows the vulnerabilities of the port and its hinterland connection to climate change.

- Moreover, some measures are described in the Rotterdam Climate Proof. For instance, the Port of Rotterdam Authority has implemented climate adaptive strategies such as:
  - Development of an office tower in Wallhaven, which can be regarded as a climate proof building. The main office tower is situated above the ground, while spaces below the tower are utilized for car parks. In case of any flooding, the car parks will be closed and the tower will be safe from flooding due to its elevation level.
  - Situate vulnerable assets far away from the areas very vulnerable to climate change.
  - There is also a discussion to develop dikes in polders in order to protect industrial activities in the port.

- The Port of Rotterdam Authority keeps monitoring those unavoidable risks, such as monitoring wind speed in the port operational area. By knowing the wind speed distribution, the port will improve its adaptive capacity towards those unavoidable risks (i.e. how to react in case of the materialization of those risks).

- To the knowledge of the respondent, the Port of Rotterdam Authority does not insure its own assets (i.e. port infrastructures) against climate risks. This is because the price or premium of such insurance is very high. Perhaps, port clients or operators are protecting their assets and revenues through insurance. This has to be later checked with them.

- All port stakeholders gain benefits from the adaptation to climate change in the Port of Rotterdam. But, the key actor that gains benefit from the adaptation is the Port of Rotterdam Authority itself. By adapting to climate change sufficiently, the port has gained reputation and sustainability in its operation, which enhances its competitiveness.

- Who is responsible on implementing and financing the measures is very dependent on the agreement. In the Port of Rotterdam, the Authority is in charge of basic port infrastructures, while the operators are in charge of providing the port superstructures and services.

- In its contract with the operators (e.g. APM), the Port of Rotterdam Authority is very transparent to the operators as the Authority informs the identified climate risks to the operators appropriately. For instance, the Authority informed the operators that the expected average sea level rise in the lease period is 50 cm and the Authority will be in charge of executing the measures to deal with the risk of rising average sea level by up to 50 cm.

- However, in case of unforeseen events, average sea level could rise at a higher rate (e.g. by 100 cm during the lease period). In this case, the private operators have to pay for the additional required measures.

- It is interesting to note that public-private partnership is implemented in executing the adaptation measures of managing the coastline of Maasvlakte 2. The measures are mainly performed by filling the coastline with sand such that port operations nearby the coastline are protected from flooding. As the measures are related to port infrastructure, the Port of Rotterdam Authority is in charge of financing it. The Port of Rotterdam Authority has hired a private contractor to perform the measure at certain design parameters. However, if the climate change evolves faster than expected, the design parameters have to be changed or strengthened. In this case, the Port of Rotterdam Authority has to pay for the extra adaptation costs.

- For measures that are associated with superstructures (e.g. road pavements or crane operations), they have to be performed and financed by the operators or clients. Moreover, if APM Terminal (i.e. the port operator) wants to raise the quay of its terminal during its lease contract, the measure has to be executed and financed by itself. However, before the execution, the port authority has to be consulted.

- The Port of Rotterdam Authority is in charge of developing sufficient port infrastructures to make the port climate adaptive. The cost of such infrastructures is high. Nevertheless, the Port of Rotterdam Authority can charge higher fees to the clients due to its reputation as a climate adaptive port. Otherwise, the fees and revenue of the Port of Rotterdam Authority will be lower. For adaptation measures that are relevant to the superstructures, the operators are in charge of financing them.

- Who is responsible for financing climate adaptation measures in ports is dependent on the terms stipulated in the contract between the Port of Rotterdam Authority and its clients.

E.3 Interview Set 3

During the research project, the author had a chance to meet and discuss climate risks allocation management in the Port of Rotterdam. From the conversation, the author obtained a plenty of important details regarding the allocation. However, the respondent refused to be formally interviewed. Therefore, it was found important to conduct the third interview set, which was aimed to validate the success factors of the Port of Rotterdam Authority in allocating climate risks and responsibilities among port stakeholders. Prof. Tiedo Vellinga, the Director of Environmental Monitoring for Maasvlakte II was approached and interviewed for this purpose. In this section, the interview protocol and summary of his responses are presented.

E.3.1 Interview Protocol

Interview Protocol	
Author	Erwanda Nugroho
Respondent	Prof. Tiedo Vellinga (The Port of Rotterdam Authority)
Date of Interview	6 June 2016
Project Title	Financing Climate Risk Management in Ports

General Instructions

Good morning. Thank you for your time and availability for this validation interview. I have written one chapter about the success of the Port of Rotterdam Authority in sharing climate risks among port stakeholders in the recent construction and concession of Maasvlakte II. The purpose of this interview is to validate my research outcomes on the success.

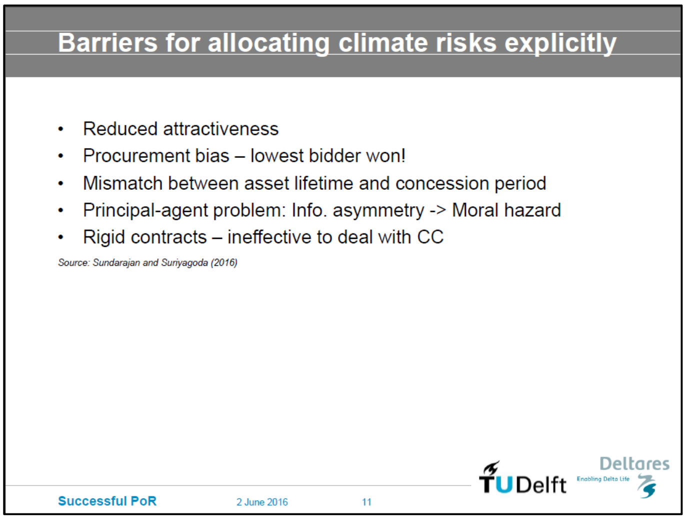
Instructions of Recording Permission

Before I start the interview, I would like to ask your permission for recording this interview. The purpose for recording our conversation is to ensure that I can get all of the details of your responses while having an attentive conversation with you at the same time. I assure you that the recording will remain confidential and only be used for the purpose of my research.

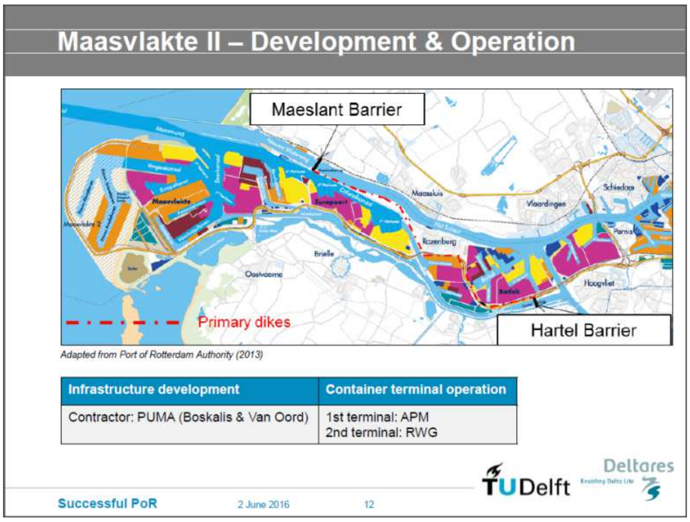
Validation of Successful Case of Climate Risks and Responsibilities Allocation in Maasvlakte II

I would like to this validation interview by presenting my research outcomes relevant to contractual agreements made for Maasvlakte II construction and operation. Whenever you feel any information is not correct or not appropriate, please stop me and let me know directly.

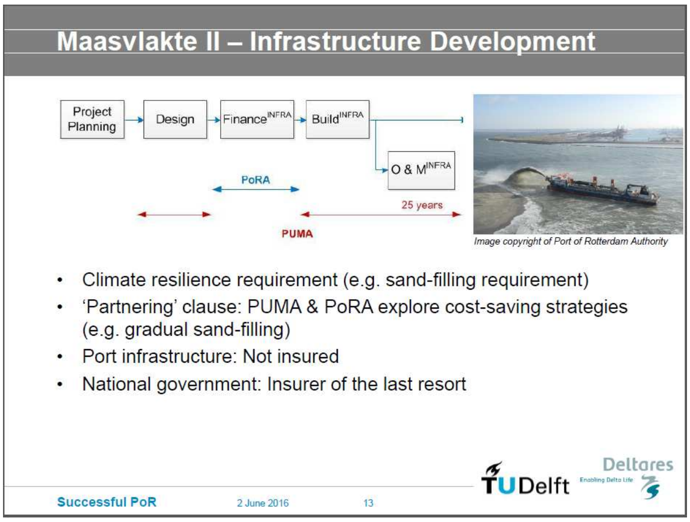
Presentation of the barriers to allocate climate risks explicitly, the slide is shown below:



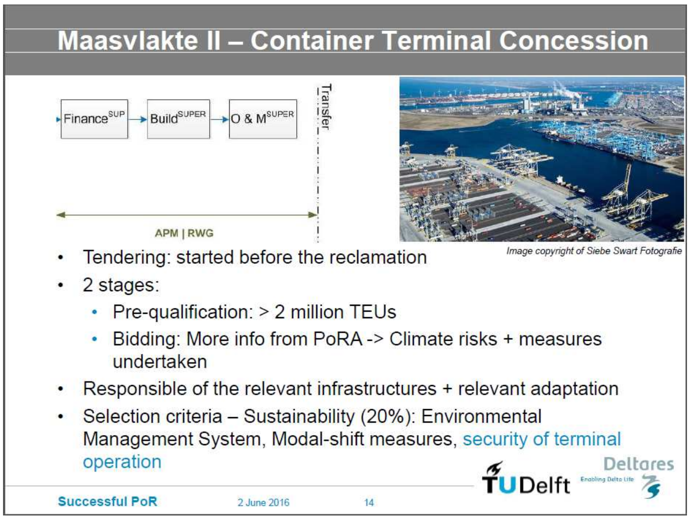
Presentation of the development and operations of Maasvlakte II, the slide is shown below:



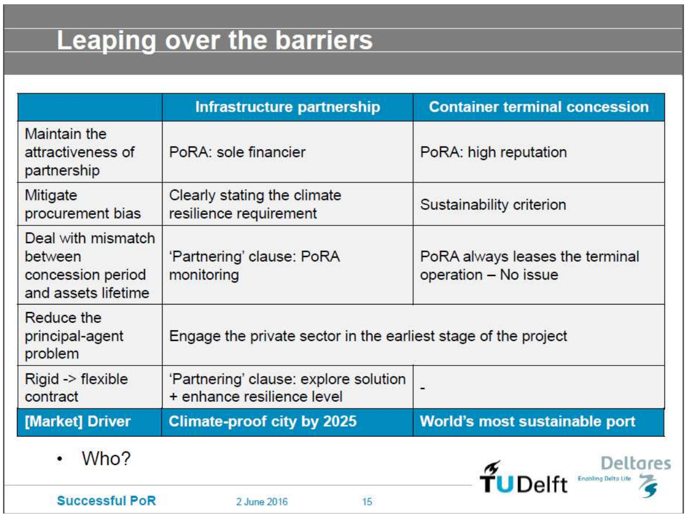
Presentation of the partnership made for the reclamation of Maasvlakte II, the slide is shown below:



Presentation of the tendering process for a container terminal operation in Maasvlakte II, the slide is shown below:



Presentation of the summary of the success factors of the Port of Rotterdam Authority in allocating climate risks and responsibilities in the development and operations of Maasvlakte II, the slide is shown below:



	Infrastructure partnership	Container terminal concession
Maintain the attractiveness of partnership	PoRA: sole financier	PoRA: high reputation
Mitigate procurement bias	Clearly stating the climate resilience requirement	Sustainability criterion
Deal with mismatch between concession period and assets lifetime	'Partnering' clause: PoRA monitoring	PoRA always leases the terminal operation – No issue
Reduce the principal-agent problem	Engage the private sector in the earliest stage of the project	
Rigid -> flexible contract	'Partnering' clause: explore solution + enhance resilience level	-
[Market] Driver	Climate-proof city by 2025	World's most sustainable port

Explicit questions, if needed:

1) What is the concession period for APM and RWG?
2) What is the existing sand-filling requirement for Maasvlakte II?
3) Is the gradual sand-filling strategy applied to Maasvlakte II or other terminal?
4) From [redacted] and Martijn de Jong, I learned that insuring assets against flooding in the Netherlands is very difficult and must be very expensive. Is this the reason of why the PoRA does not insure its infrastructures?
5) Is it clearly stated in the contract that the national government will do something if any adverse climatic event occurs?
6) In the sustainability criterion, I saw one of the components is security of terminal operation. Does this include the sustainability of the operation in case of bad weather events?

E.3.2 Summary of Responses

- The terminal that is currently being operated by APM Terminal is referred to as the second container terminal of Maasvlakte II, while Rotterdam World Gateway is the first container terminal of Maasvlakte II.

- Interested port operators were not explicitly required to state their proposed operational plans during adverse climatic events in the tendering of the first container terminal of Maasvlakte II.

- Insuring assets against climate risks in Maasvlakte II are way too expensive, as stated by [redacted] and Martijn de Jong.

- The concession periods for the APM Terminal and the Rotterdam World Gateway are both 25-year.

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