Flexible port infrastructure on Maasvlakte 2
How to make use of the temporary inner lake

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Master Thesis
Final report

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Preface

This thesis presents the final project of my Master Civil Engineering at Delft University of Technology. The project has been carried out in the framework of the ongoing PhD research project “Flexible Port”. It enabled me to work on a topic and in an environment that has always fascinated me. As a child, I spent hours watching TIR trucks passing by my house, digging transport routes in the garden and dredging channels on the beach. It is a great pleasure for me to participate in Rotterdam’s latest port expansion project, Maasvlakte 2.

During the project I have been advised by my Graduation Committee and many colleagues from Port of Rotterdam Authority. This helped me in making the topic better understandable and the project more enjoyable. Therefore I would like thank:

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Dank oe wa! Vielen herzlichen Dank an euch! Merci les gars! Thanks!

Robin Ros, Rotterdam, 15 December 2011

Summary

Background information
Port of Rotterdam Authority develops the Port of Rotterdam and promotes the safe and efficient handling of shipping in its channels and approaches.

Economic growth and shifting labor markets have induced a worldwide increase in maritime transport. The Port of Rotterdam has a direct round the clock deep sea connection and handles a considerable amount of the cargo that enters and leaves the European market. The increase in throughput has led to a scarcity of space for new companies, and existing clients wishing to expand. To cope with this demand, Port of Rotterdam Authority decided to construct Maasvlakte 2.

Maasvlakte 2 is a business case driven project. The outcome of the business case has led to the construction of an entire sea defense and the realization of port areas in phases, in response to client demand. The phased development results in the creation of a temporary inner lake. The temporary use of this inner lake by port activities is hampered by the large investments generally required for port infrastructure.

- ➢ This research examines the possibility of allocating temporary activities to the temporary inner lake of Maasvlakte 2, using flexible port infrastructures.

Alternatives for the inner lake
Potential activities are inventoried and ranked in a brainstorming session. Potential structures are investigated through a literature study. Activities are coupled with structures to create alternatives. These are allocated on the inner lake, depending on their functional requirements. The common barge terminal is the only activity that requires a quay type structure. The objective of this research is to examine the financial viability of an activity using a flexible structure. The common barge terminal concept is examined in detail.

Common barge terminal
A common barge terminal is a neutral transshipment point that enables inland vessels to transship their containers at one inland quay instead of at several deep sea quays. Its results in a win, win, win situation:

- Inland vessels operators do not have to hop from one terminal to the next. They sail shorter distances and can reduce their turnaround time in the Port of Rotterdam.
- Container terminal operators have more time and space to handle sea going vessels. Sea going vessels are served by more cranes and can transship more containers per time per quay length. The additional quay capacity enables to postpone expansions.
- Port of Rotterdam Authority can postpone deep sea quay expansions.

The latter is examined in detail. Port of Rotterdam Authority can postpone several deep sea quay expansions. There are three container terminal operators on Maasvlakte 2 that want to expand in several phases. Postponing deep sea quay expansions saves investment costs and leads to a loss in rent. The future value of costs and revenues are lower than the present value. A discount factor reduces future to present values. The net present cost savings cumulates the discounted cost savings and losses in rent of all postponed expansions.

The net present cost savings for Port of Rotterdam Authority are larger than 15 M€, if the:

- Inland vessels that call with 50 TEU or less are handled at the common barge terminal,
- Discount rate is at least 8.5%,
- Percentage transshipped in call sizes <50 TEU is at least 4.2% of the total throughput and the increase in container throughput is at most 6% OR the percentage is at least 2.1% and the increase is at most 3%.

Port of Rotterdam Authority not only saves cost with a common barge terminal, but also has to invest in a quay and receives rent from the common barge terminal operator. Several structures are compared by their whole lifecycle costs. Containerland consists of several containers sandwiched between two concrete slabs and has the lowest whole lifecycle costs.

The service life of the inner lake is considerably shorter than the technical lifetime of the structures. Structures can be reused, sold or demolished. Reuse-possibilities have to be considered in case the rest value after the service life of the inner lake is large. Port of Rotterdam Authority can generate 3 M€ rest value (about 40% of the net present value) in case the service life is 10 years and the discount rate 8.5%. The rest value is 5 M€ in case the service life is 5 instead of 10 years and 7 M€ in case a discount rate of 4.5% is used instead of 8.5%.

Portfolio analysis

The monetary and non-monetary value of each alternative is captured in a balanced score card. It illustrates the short term (net present value & costs), the intermediate term (sustainability, synergy, safety) and the long term (innovation) effects for Port of Rotterdam Authority. A portfolio matrix evaluates the profitability of each alternative against the competitive strength and market attractiveness. It indicates whether Port of Rotterdam Authority should start to realize, further investigate, wait or stop with the alternatives:

Start:

- Liquid bulk transshipment has a net present value of about 7.5 M€. Ship-to-ship transshipments are more costly at the inner lake, but safer than at the North Sea.

Investigate:

- Dry bulk storage has a net present value of about 2 M€. Storage is carried out at the existing contractor quay wall at a small scale, i.e. hindrance is negligible.
- Wind turbine assembling facility has a net present value of about 2.2 M€. It can benefit from Rotterdam's hinterland connections and offshore cluster.
- Mooring spaces for inland vessels have a negative net present value. They are required in case many vessels have to wait at a quay.
- Common barge terminal has a net present value of 8 M€. It creates a win, win, win situation. Moreover it serves as pilot project for flexible structures.
- Mussel farmers have to switch from a bottom to a floating harvesting method. Floating ballasted structures can be realized as pilot on the inner lake and applied elsewhere.
- Nature develops anyhow due to attractive site conditions of the inner lake. The inner lake can function as acclimatization, spawning area or food stock. New regulations on temporary nature avoid hindrance to the development of Maasvlakte 2.

<u>Wait:</u>

- Mooring spaces for feeders are required in case many vessels have to wait at a quay. Feeders have a higher priority than inland vessels.
- Wind energy has a net present value of about 1.5 M€. Wind turbines have payback periods of 10 years or more, cause noise, form an obstacle and require large safety distances to other activities.
- Algae farming is financially viable as high quality supplement in food and cosmetics. Many small scale pilot projects are already projected to render algae viable as fuel, as conditioner in fish farms or as neutralizer in waste water treatment.
- Hotel at work can house workers from 2015 in a floatel at the inner lake. This reduces commuter traffic.

<u>Stop:</u>

- Fast ferry can reduce the usage of private transport. Activities on the inner lake and Maasvlakte 2 do not generate enough passengers. Furthermore commuters prefer private over public transport.
- Water sports can only take place at a certain safety distance. Kite and wind surfers can use the inner lake as alternative with milder conditions to the beach at Maasvlakte 2.
- Dolphinarium has to attract as many visitors as possible. Port of Rotterdam Authority wants limit the number of people on Maasvlakte 2 for safety reasons. Furthermore the dolphinarium in Harderwijk attracted fewer visitors over the past years.

Conclusions

The results of this research enable Port of Rotterdam Authority to respond different future scenarios with port, other than port or a combination of activities and generate about 20 M€. The top financial alternatives are a liquid bulk transshipment facility, common barge terminal and wind turbine assembling facility. The top non-financial alternatives are mussel farming and a temporary nature reserve.

Modular structures with single use component have the lowest whole lifecycle costs. Reuse-possibilities have to be considered in case the discount rate is low (4.5 instead of 8.5%) or the service life is small (5 instead of 10 years).

Recommendations

Port of Rotterdam Authority could realize one liquid bulk transshipment facility and permit a pilot for mussel farming. It could estimate the profits and losses for the container terminal operators on Maasvlakte 2 through the use of a common barge terminal, clarify the opportunities and treats of new regulations on temporary nature and estimate the number of offshore wind farms.

Port of Rotterdam Authority could determine a portfolio of best structures. The whole lifecycle costs of potential structures have to be compared with the structures in the Port of Rotterdam and its hinterland for several retaining heights and slopes. The most suitable structures can be implemented as standards in the market.

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Definitions & abbreviations

Definitions

Alternative	is an option for the inner lake that includes an activity and a port infrastructure.
Activity	is something that can be done to fulfill a certain need. Port activities transport, transship, store cargo and require nautical access. Other activities have no direct relation with a port and can take place elsewhere
Business case	is an economic calculation model that verifies the financial viability of projects continuously, in order to make up to date decisions.
Common barge terminal	is a central transshipment point for inland vessels. It enables inland vessels to pick up their cargo at one neutral terminal, instead of at several terminals.
Discount rate	is a percentage at which the value of costs and revenues decrease over time; (i) inflation, (ii) rather cash today than tomorrow, (iii) the risk of not materializing cash. It is used to calculate the net present value of the alternatives.
Market	is a place where products are exchanged from sellers and to buyers. Port of Rotterdam Authority lets its port infrastructure to terminal operators and shipping companies and receives rent and port dues in return.
Net present value	is the sum of the discounted costs and revenues over the lifetime of a project. Alternatives with a positive net present value are profitable.
Port infrastructure	is the product of Port of Rotterdam Authority. It consists of supra, supportive and basis structures.
Rest value	is the additional net present value that can be generated when reusing a structure twice after the service life of the inner lake.
Structure	is a part of the port infrastructure that is responsible for the stability.

Abbreviations

LOA	Length Overall (unit of measurement for the length of a vessel)
M	Million
m	meter
NAP	Normaal Amsterdams Peil (Amsterdam Ordnance Datum)
K	Thousand
s	seconds
TEU	Twenty-foot Equivalent Unit (unit of measurement for containers)
y	year

1 Introduction

This chapter describes the trigger of this research and its approach. Section 1.1 presents the development of the Port of Rotterdam and its latest expansion project Maasvlakte 2. Section 1.2 and 1.3 define the problem and objective for this research. Section 1.4 and 1.5 illustrate the research approach used to tackle the problem and the outline of this thesis.

1.1 Background

Maasvlakte 2 is an expansion of the Port of Rotterdam initiated to keep up with the forecasted demand for space in the port. The project is managed as a business case to make optimal decisions over the years in a changing environment.

Economic growth and shifting labor markets have induced a worldwide increase in maritime transport, using ever increasing ship sizes and therewith larger draughts. The Port of Rotterdam has expanded its entrance towards the North Sea and ensured in this way a direct round the clock deep sea connection *(see Figure 1-1).* For this reason a considerable fraction of the cargo enters the European market via the Port of Rotterdam [36]. However, the ever increasing throughput has led to a scarcity of space for new companies, and existing clients wishing to expand. To cope with this demand and to reinforce the international competitive position of the port and the industrial complex, Port of Rotterdam Authority decided to construct Maasvlakte 2 [35].

Maasvlakte 2 is an expansion on reclaimed land, carried out in several stages. It increases the port area with 2,000 hectares to a grand total of 12,000 hectares. Its channels have a water depth of 20 meters, giving access to the largest new generation vessels [51].

Figure 1-1: Development of the Port of Rotterdam over the past 600 years from Rotterdam's city center to Maasvlakte 2 at the North Sea

The development of Maasvlakte 2 is driven by the outcomes of a business case. A business case considers costs, revenues and risks of several stages and justifies the best option, including doing nothing. This could induce the termination or amendment of a project, if the business need abates or changes. The business case of Maasvlakte 2 induced a phased construction to match clients' demands. This avoids the creation of capital-intensive sites without revenues and enables Port of Rotterdam Authority to anticipate on exogenous uncertainties in the future.

As a result of this business case the sea defense is constructed at once and the port areas in several stages. A large water area on Maasvlakte 2 is temporarily not used. This inner lake remains idle after the inauguration of the first stage in 2013 for about 5 to 15 years *(see Figure 1-2)*. It measures 500 hectares and has a water depth in the inner lake that ranges from 14 to 17 meters [35].

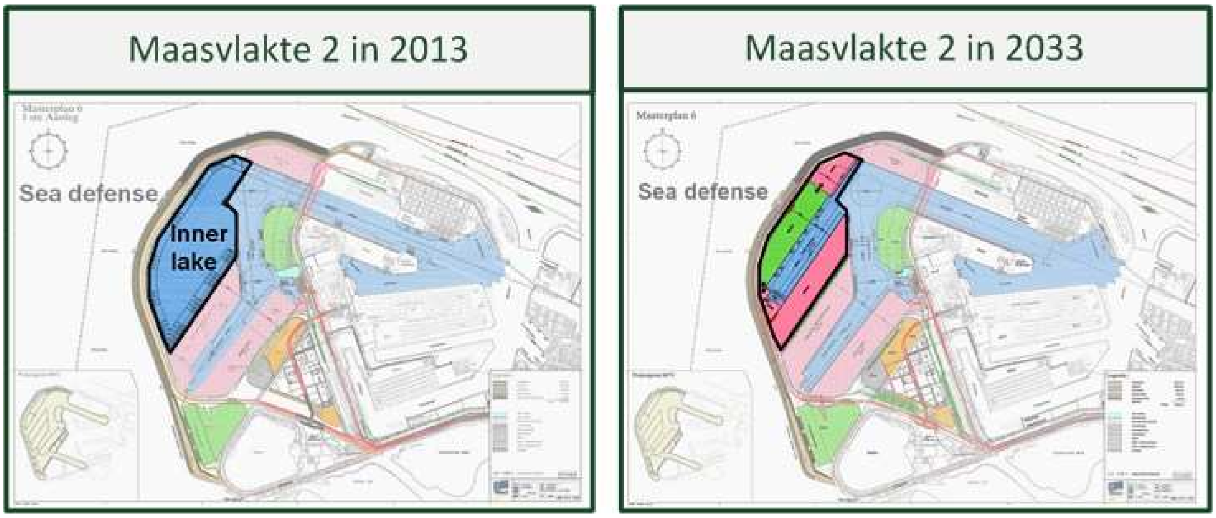


Figure 1-2: Development of Maasvlakte 2 in several stages, in order to match clients' demand; (left) the first stage in 2013 with temporary inner lake and (right) the final stage around 2033 completely in use

1.2 Problem description

The forecasted demand for space and scarcity of available port areas has led together with a positive outcome of the business case, to the creation of Maasvlakte 2. The choice of phased construction in response to client demand has led to a temporary inner lake; an opportunity to develop temporary activities. Temporary use of the inner lake is hampered by the complexity of modern port activities and the large investments generally required for common port infrastructure.

1.3 Research objective

This research examines the possibility of allocating temporary activities to the temporary inner lake of Maasvlakte 2, using flexible port infrastructures. Several alternatives for temporary use are examined in a business case as to their financial viability. The ability of such alternatives will enable the Port of Rotterdam Authority to respond quickly to different future scenarios and will help strengthen its competitive position as logistics hub and world-class industrial area.

1.4 Research approach

The examination of the financial viability of several activities on the temporary inner lake comprises various aspects and cannot be carried out overnight. A stepwise method based on Systems Engineering is used to achieve the research objective *(see Figure 1-3)*. Systems Engineering is an integral approach that reduces a problem's complexity by considering alternatives at several scales. Elaborating these alternatives over the project's lifecycle back and forth specifies the alternatives' consequences and enables project's initiators to support their decision [71]. Step 1 defines the research objective from the background information *(see Section 1.1-1.3)*. Following steps analyze site conditions, construct and evaluate alternatives, in order to make a decision on how to use the inner lake with port infrastructure.

Step 2, 3 and 4 describe the site conditions and alternatives for the temporary inner lake. Step 2 presents the site conditions of the inner lake. The site conditions determine whether alternatives can take place on the inner lake. Step 3 collects activities and structures for the inner lake. Potential activities are collected and ranked in a brainstorming session. Interviews and literature research specify activities. Structures are described with by literature. Step 4 links potential activities with potential structures to alternatives and allocates them on the inner lake based on their functional requirements. One alternative, the common barge terminal, requires port infrastructure and is elaborated further.

Step 5 evaluates the alternatives for the temporary inner lake by their financial viability, added value and market approach. A financial analysis determines whole lifecycle costs and revenues of the alternatives. The non-monetary value of the alternatives is illustrated with a balance score card. A portfolio analysis indicates on which alternatives investments can take place and what their implementation risks are. Step 6 recapitulates the main conclusions of this research and recommends Port of Rotterdam Authority which alternative should take place on the inner lake.

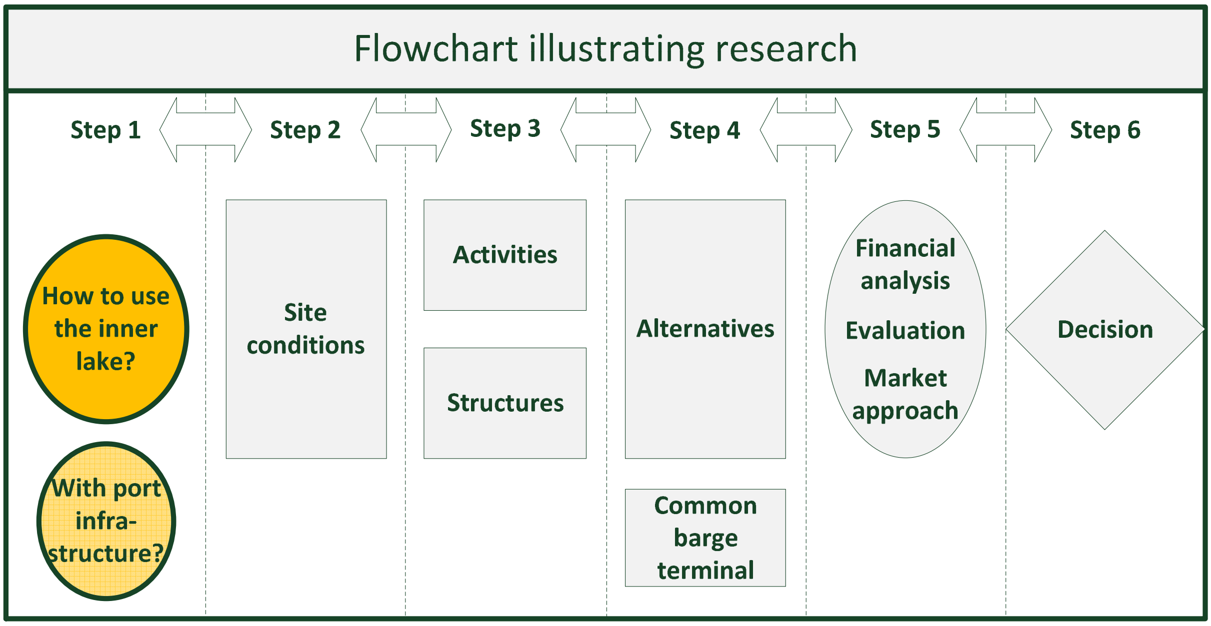


Figure 1-3: Flowchart illustrating research; from problem description to decision by making use of the elementary design cycle (as roadmap of this research at the beginning of each chapter, shapes of current step filled with orange & bounded by larger lines)

1.5 Thesis outline

This thesis is structured as follows:

Chapter 2 describes the geometry, tides, wind and wave conditions of the inner lake and policies, development plan and vision of Port of Rotterdam Authority.

Chapter 3 illustrates the brainstorming method that is used to come up with, group and rank activities. The most promising activities are described.

Chapter 4 recapitulates bottom founded and floating port infrastructures.

Chapter 5 combines potential activities with port infrastructure to alternatives and allocates them on the inner lake by their functional requirements.

Chapter 6 elaborates the principle of the common barge terminal. Handling inland vessels with small call sizes at a neutral terminal increases the deep sea quay capacity. The additional capacity can be used to postpone deep sea quay investments.

Chapter 7 calculates the financial viability of each alternative. Costs and revenues are determined per lifecycle phase. Scenarios on the service time of the inner lake, reuse-possibilities and different discount rates indicate the bandwidth of the net present value.

Chapter 8 derives evaluation criteria from the port vision. Alternatives are evaluated with monetary and non-monetary criteria in a balanced score card.

Chapter 9 classifies the alternatives in a portfolio and risk matrix. Market attractiveness, competitive strength and profitability ratio indicate which alternatives should take place on the inner lake. The market and technology familiarity indicate their implementation risks.

Chapter 10 recapitulates the main conclusions of this research. Recommendations indicate which alternatives can take place on the temporary inner lake and how flexibility can be incorporated in a design approach.

Appendix A presents additional information on the activities. All activities that are collected in the brainstorming session are illustrated. Some non-feasible activities are described. A quantification of the extent of the activities enables to calculate the revenues. Different values of the input parameters indicate the bandwidth of the net present value.

Appendix B specifies structures' dimensions and whole lifecycle costs. The alternatives' functional requirements and reference projects determine structural dimensions. Several graphs present the cost components, compare the investment costs with key figures and indicate whether reuse-possibilities have to be considered.

Appendix C calculates the business case of a common barge terminal for Port of Rotterdam Authority and the common barge terminal operator.

2 Site conditions

This chapter describes the site conditions. Section 2.1 illustrates the geometry, tides, wind and wave conditions of the inner lake. These conditions determine whether an activity can take place. Section 2.2 defines the allocation policy, development plan and port vision of Port of Rotterdam Authority. These documents determine whether an activity will take place.

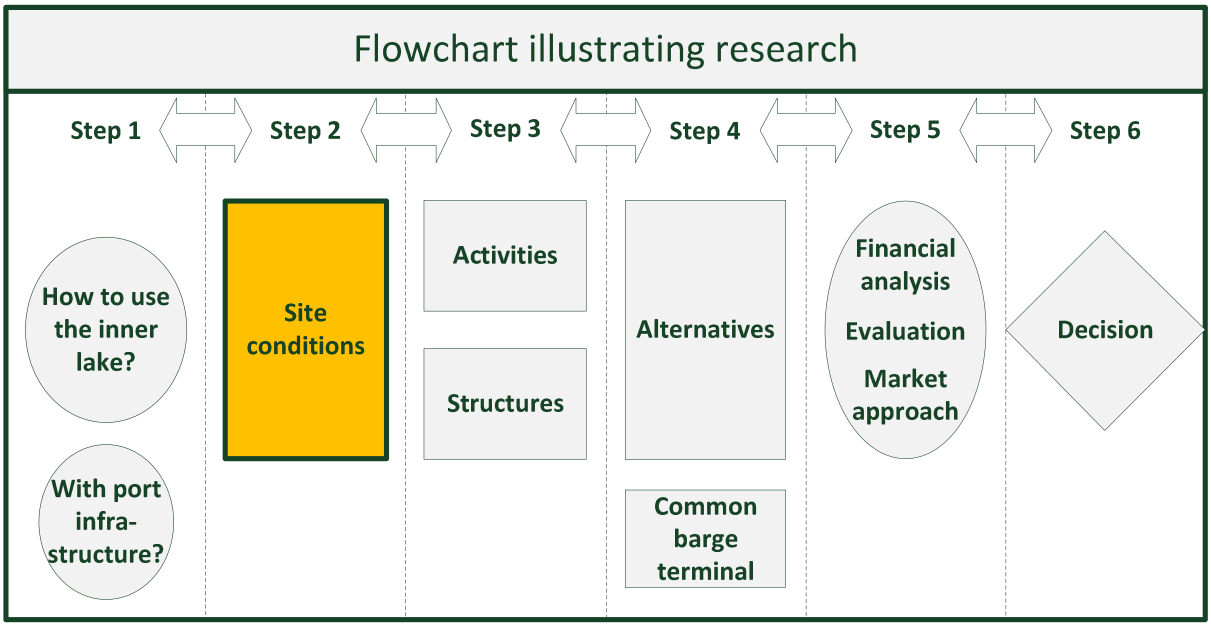


Figure 2-1: Flowchart illustrating research, chapter 2; geometry, tides, wind, wave conditions (can an activity take place) and policies, development plans, port vision (will an activity take place)

2.1 Geometry, tides, wind and wave conditions

The geometry describes the adjacent sites and dimensions. The wind, waves and tides describe the amplitudes and velocities of air and water [10]. Together these conditions determine activities are on the inner lake, if so, what flexible port infrastructure they require. Geometry, tides and wave conditions can vary over time. During this research there were several discussions over the water depth of the inner lake.

Geometry
The inner lake measures about 500 hectares and has a water depth varies from 14 m in the south-eastern part to 17 m in the north-western part of the inner lake. The soil consists of fine to medium sized sand, is quite rectangular shaped and has a low finer percentage [35]. The inner lake is allocated between the Euromax container terminal in the north-east, the Prinses Arianehaven in the east, the RWG container terminal in the south-east and the sea defense in the west. These adjacent areas have different ground levels. The bottom of the Prinses Arianehaven is allocated at -20 m NAP and the ground level of the other sites at +5 m NAP. The different ground levels of the inner lake and adjacent areas are connected with a natural slope of 1/10. Furthermore there are three quay walls at the northern part of the inner lake, used by the contractor of Maasvlakte 2 to construct the sea defense *(see Figure 2-2)*.

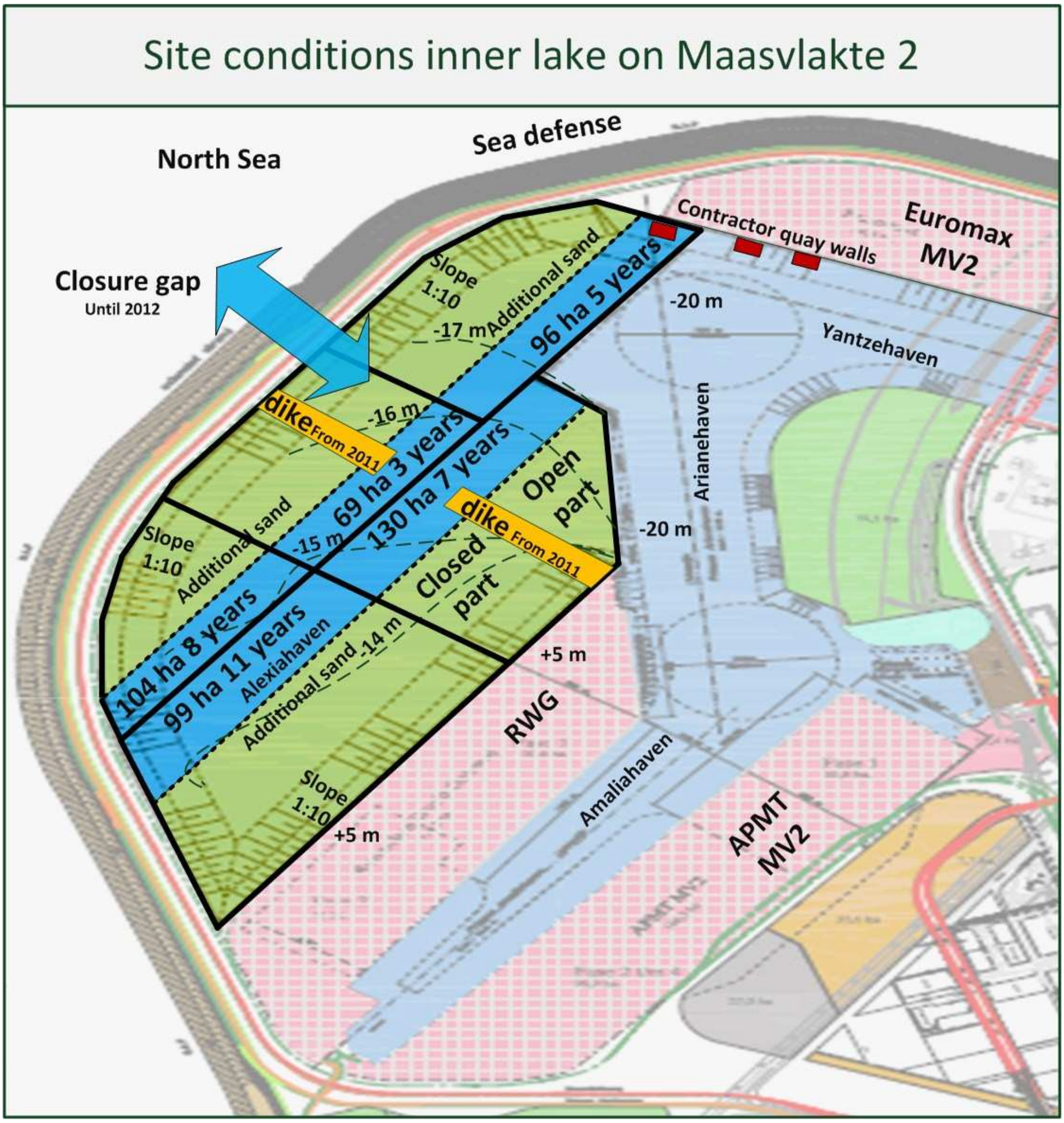


Figure 2-2: Inner lake divided into five parcels with size (in hectares) , expected available time (in years), adjacent sites, temporary dike, contractor quay walls, closure gap and location of additional sand

Additional sand

During this research the construction of a dike started that separates the inner lake into two parts. A closed dike will decrease the amount of water that flows in with the tide through the closure gap in the sea defense. The gap can be closed easier, i.e. less material and equipment required *(see Figure 2-2)*.

The dike that separates the inner lake into two parts is opened, after the gap in the sea defense is closed and the Yantzehaven is expanded. This break-through will take place in 2012 and enables ships to reach the south-western part of the inner lake *(see Figure 2-2)*.

There was also a discussion going on about whether sand for the final phase should be stored at the inner lake. Sand is probably needed to create land for future terminals on the inner lake and can be allocated along the future Alexiahaven *(see Figure 2-2)*. Despite an attractive market price was offered by the contractor, the outcome of the business case of Maasvlakte 2 indicated that buying sand later is more favorable. Not only the market price of sand, but also the demand for port areas varies over time. Bringing sand in stages enables Maasvlakte 2 to be adaptable to future developments.

Wind, waves, tides
Wind speeds vary per direction and over the year. The wind direction varies for about 50% of time between south and west and ranges for about 70% of time from 3.5 to 10.7 m/s. High wind speed appear especially in winter time from the north. Wave heights and periods vary over the inner lake and increase in downwind direction. The wave height is limited because the natural slope barely reflects any wave energy. The significant wave height does not exceed 0.8 m and wave period does not exceed 3 s [10]. The semidiurnal tide generates a vertical and horizontal water motion. The vertical motion changes the water level over time. The water level ranges from -0.75 to 0.90 m NAP. The horizontal motion changes the water velocity over time. The average velocity in the inner lake ranges from 0 to 0.2 m/s and in the Yantzehaven from 0 to 0.8 m/s [10]. The visibility amounts for about 95% of time more than 2000 m [48].

2.2 Allocation policy, development plan and port vision

Even if activities were surfable and function on the inner lake, their realization might be hampered. Port of Rotterdam Authority decides whether activities and, if so, where activities take place. The port's environment is influenced by activities on the inner lake. Several parties could start procedures, in order avoid negative impacts.

The core tasks of Port of Rotterdam Authority are the handling of vessels in the port and the development of port areas. Safe and efficient handling of shipping in the port is ensured by nautical services, such as a traffic management system, traffic control systems and patrol vessels. The development of port areas comprises on one hand market activities, such as the long-term spatial planning, allocation of sites and the negotiation of lease prices with tenants and on the other hand technical activities, such as the construction and maintenance of port infrastructure [36].

Sophisticated development of the port areas is very important. Most business decisions in the maritime sector are related to long term developments. Port companies often have to make large investment and strive for long term cost optimization by locational advantages, such as network effects [36].

Shipping companies call at ports that minimize transport costs over the total logistical chain. These costs are mainly determined by nautical and hinterland advantages and cannot be influenced in the short run. Port of Rotterdam Authority has realized long term cost advantages in the Port of Rotterdam and obtained large market share in the Hamburg – Le Havre range [36]. In order to ensure a successful long term development Port of Rotterdam Authority has set up several frameworks:

- The allocation policy verifies the business profile of the prospective tenant, elaborates the optimum use of space, integration into surroundings and financial terms. Port activities generate additional throughput in the port and generate Port of Rotterdam Authority rent and port dues. Other activities can support port activities and generate added value for the port area [57].
- The development plan describes how Maasvlakte 2 will be constructed and what the environmental impact will be:
  - The masterplan indicates, amongst others, from when sites will be in use by clients. This indication can be used to estimate the availability of the inner lake. About two years before the inauguration of the sites, the construction of port infrastructure starts [35]. At this moment temporary activities and port infrastructure should be removed completely. The average expected availability amounts only 7 years and is rather short for common port activities *(see per parcel Figure 2-2)*.
  - The environmental impact assessment ensures a healthy development of the port in harmony with the surrounding area. The outcome of this assessment has led to a nature compensation area of 750 hectares. Environmental thresholds are monitored with indicators, such as air quality [35].
- The port vision derives from different economic scenarios the future effects on demand for space in the port, connections with the hinterland and the environment. Based on these findings it proposes strategies, in order to strengthen the Port of Rotterdam's competitive position as logistics hub and world-class area [53].

These frameworks are entwined with governmental policies and include therewith the interests of the port's environment. Municipality of Rotterdam and the Dutch state are the shareholders of Port of Rotterdam Authority and can enforce their interests in shareholders' meetings [57]. Furthermore rules and laws can prohibit activities on the inner lake. Rules and laws on safety (nautical, intrinsic, external), species protection (European Bird and Habitat Directive), nature protection (Nature 2000), spatial planning (Dutch spatial planning and water law) apply only to some activities [35] [50].

2.3 Conclusions

This chapter described the site conditions of the inner lake:

1) The geometry, wind-, wave- and tide conditions determine if an activity is possible.
   a) The construction of a dike has started that will separate the inner lake into two parts. The moment at which the dike opens again and the width of the opening are still unknown. Besides the dike no additional sand is brought into the inner lake.
   b) The inner lake is located in the North Sea and has offshore wind conditions.
   c) The tidal influences and wave conditions in the inner lake are rather limited.

2) The port's policy, development plan and vision determine if an activity is feasible:
   a) The allocation policy determines the suitability of activities in the port.
   b) The masterplan determines the availability of the inner lake for temporary activities. Environmental thresholds determine the environmental impact assessment.
   c) The port vision describes the strategic choices on Port of Rotterdam Authority's.
   d) The short availability of the inner lake is unusual for port infrastructure. It is the most important boundary condition.

3 Potential activities

This chapter describes what potential activities can take place on the inner lake. Section 3.1 illustrates the literature and brainstorming method that is used to gather, group and rank activities. Section 3.2 describes potential port activities and other activities.

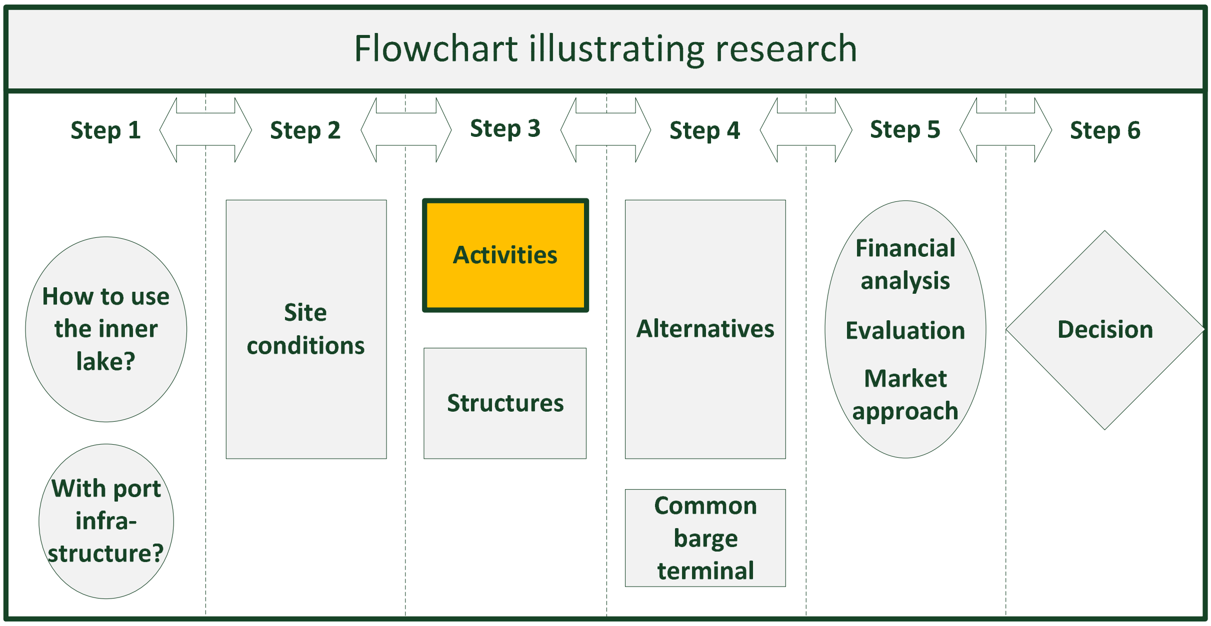


Figure 3-1: Flowchart illustrating research, chapter 3; description of literature, brainstorming method to inventory port activities and other activities

3.1 Inventory of potential activities

Literature

First ideas on potential use of the temporary inner lake on Maasvlakte 2 are described in two documents. This research uses this literature to get an insight in the possibilities for the inner lake and to build on existing knowledge. Potential activities are presented in the development plan of Maasvlakte 2 and in an internal document for temporary use of the inner lake:

- The development plan of Maasvlakte 2 describes briefly the situation of the inner lake and proposed several activities: Waiting berths for inland shipping & salvage enterprises, mooring facilities for ship-to-ship transshipment & offshore equipment, storage facilities for construction materials, large construction elements & empty containers and an information center [35].
- The internal document for temporary use of sites on Maasvlakte 2 lists all activities that have been collected in three workshops for the project organization Maasvlakte 2. Furthermore it lists the functional requirements of the most promising activities in a table. The internal document also proposes an organizational set up for the acquisition of temporary activities [58].

Brainstorming session

The list of potential activities from the literature inventory is extended by conducting a brainstorming session. Potential activities can be collected in several ways. The chance to collect a large number of high potential activities increases as one involves its full network, sets a sufficient large scope and uses an efficient ranking system [3]:

- The involvement of the full network enables to collect activities Port of Rotterdam Authority has not thought of. Companies cannot recognize all potential activities themselves. More new business ideas originate from business partners than from full-time employees [61]. The brainstorming session is carried out with people from Port of Rotterdam Authority, Municipality of Rotterdam and Delft University of Technology [46].
- A sufficient large scope means diverse activities. The number of potential port activities with short payback periods might be limited. They might not require the available area of 500 hectares. Some parts of the inner lake stay unused. Therefore the scope of the brainstorming session is extended from port activities to other activities.
- An efficient ranking system saves time. A larger collection of potential activities implies larger differences in viability and requires more time to evaluate. The brainstorming session separates potential activities from feasible activities by a single criterion.

The brainstorming session was carried out in several steps. First, the site conditions were described for the participants. Second, ideas were gathered individually and arranged, together with the activities from the literature, by their relation to the port *(see Figure 3-2 and Appendix A.1)*. Third, potential activities were ranked on their overall feasibility.

The classification of activities is made by functional requirements. Port activities involve transporting, storing or transshipping cargo. They require nautical access, port infrastructure and can only take place in a port *(see Section 3.2.1)*. Other activities produce products, serve people or nature. They might require waterside access and structures as well, but usually take place out of a port *(see Section 3.2.2).*

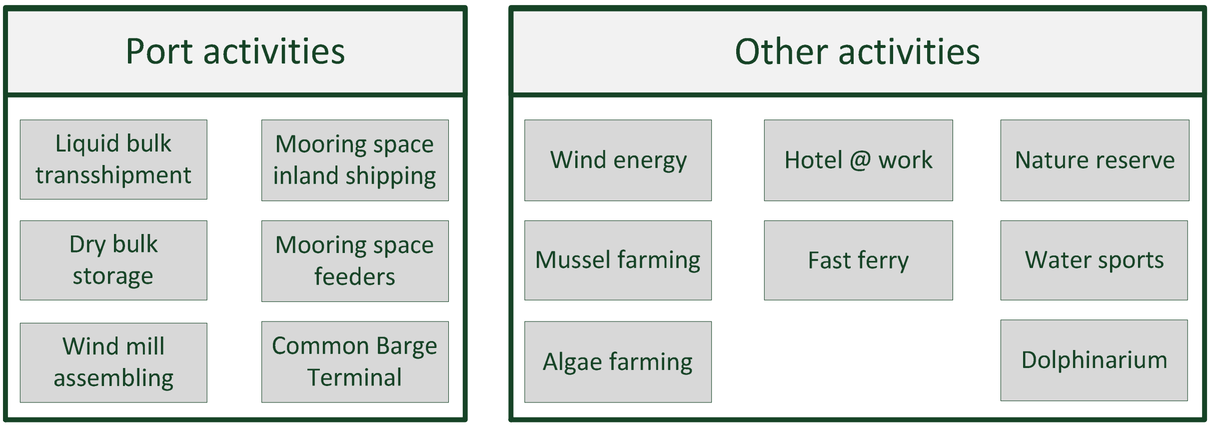


Figure 3-2: Activities that have been gathered in a brainstorming session grouped by port and other activities, ranked on their overall feasibility

3.2 Description of potential activities

3.2.1 Port activities

Liquid bulk transshipment

Ship-to-ship transshipment is a process, in which cargo is transferred from one ship to another. Two ships are positioned alongside each other in relatively calm weather conditions, moored with buoys or piles and berthed with ball shaped fenders *(see Figure 3-3)* [18]. Ship-to-ship transshipment is suitable for unpredictable trading, small and fast growing markets. Traders make fast sell or buy decisions and search for transshipment facilities on the short term. Ship-to-ship transshipment saves intermediate storage and can be carried out at more locations than ship-to-shore transshipment [49]. Small or uncertain fast growing markets make large investments in liquid terminals unviable. Cheaper and more flexible ship-to-ship transshipment facilities can render investments financial viable [49]. Moreover liquid bulk terminals are less interested in ship-to-ship transshipment, as they generate fewer revenues than ship-to-shore transshipment [49]. Port of Rotterdam Authority has created four multi-user berths in the Calandkanaal. The occupancy rate of these berths is high, even though other locations at the North Sea are free of port dues. The first facility had a payback period of about one year [49]. The demand for transshipment facilities in the Port of Rotterdam can rise further. Spillage risks increase public resistance against ship-to-ship transshipments at Suffolk (UK). Although more reliable hoses appear on the market, mild wave conditions on the inner lake and nearby patrol vessel with spillage screen can increase safety considerably [52][60].

Figure 3-3: Ship-to-ship transshipment Scapa flow (UK); (top left) mooring approach, (top right) coming alongside, (bottom left) mooring with tug, (bottom right) connect hoses [18]

Dry bulk storage of granite blocks

Granite blocks are imported with small vessels from Norway to the Benelux. Small vessels have a small draft and can be berthed at port facilities with small retaining depths *(see Figure 3-4, right)*. The three quays at the inner lake, used for the construction of the sea defense, can be used for the transshipment of granite blocks *(see Figure 2-2)*. However, other ports in the Hamburg – Le Havre range with similar port facilities could be used as well. The Port of Rotterdam is especially attractive for its hinterland connections. Storage of sand and gravel at the inner lake is unviable *(see Appendix A.2).*

Figure 3-4: An importer of granite blocks can make use of the contractor quay wall at Maasvlakte 2; (left) a bunch of granite blocks and (right) a self unloader used to transport dry bulk from Norway to the Benelux [30]

Wind turbine assembling

Offshore wind turbines are produced in components in factories and transported to ports, where they are assembled to larger components. Offshore equipment transports larger components seawards and assembles them to offshore wind turbines *(see Figure 3-5, right)*. The European Union aims at a percentage of renewable energy production to the total energy production of at least 20% until 2030. National governments have targeted offshore wind energy projects in the North Sea for a grand total of 72 GW *(see, Figure 3-5, left)*.

Figure 3-5: Wind turbine assembling; (left) European governments around the North Sea have set targets of 72 GW wind energy total in the North Sea [66] and (right) wind turbine assembling with a vessel that berths alongside at Burbo banks (UK) [59]

About 1.5 GW is installed so far. Meaning that about 14,000 5 MW wind turbines needs to be installed in the next 19 years or about 2 per day [16]. Limited availability of suitable ports and offshore equipment, increasing sailing distances to wind farms and large operational downtimes triggered a consortium to make a preliminary design for a wind turbine assembling port in the North Sea [66]. However, the large investments required for an offshore port and the development dedicated offshore equipment tend to allocate wind turbine facilities in existing ports [59]. Most British ports are privately owned and unwilling to invest in a niche market that depends highly on subsidies [59]. Rotterdam's offshore cluster, its excellent hinterland connections where wind turbine factories are allocated and the coincidence of the inner lake's availability with energy targets till 2030 are attractive preconditions for a wind turbine assembling facility at the inner lake.

Mooring spaces for inland vessels & feeders

Vessels have to wait when quays are occupied. Terminals prioritize sea going vessels over feeders and inland vessels as they generate more revenues. Moreover sea going vessels have agreements on service times. Exceeding service times result in fines and lead to a loss of customers [55]. Vessels have to wait at mooring spaces *(see Figure 3-6)*. About 20 mooring spaces were appointed to two terminals at Maasvlakte 2 so far. At Maasvlakte 1 there are about 80 mooring spaces for four terminals [51]. Although throughput increase and change in modal shift will increase inland shipping with 400% in the next 25 years, additional mooring spaces are not necessarily required [53]. A traffic management system based on the Just-In-Time principle is developed to decrease the waiting times in the port [53]. Mooring spaces can be allocated at the inner lake, until the traffic management system is operational. Facilities for nautical services and offshore equipment are not required *(see Appendix A.2).*

Figure 3-6: Mooring spaces at Maashaven, Rotterdam (NL); (left) top view and (right) side view

Common barge terminal

Inland vessels usually have to pick up their containers at several terminals in a port *(see Figure 3-7, left)*. A common barge terminal enables inland vessels to transship their containers at one terminal, instead of at several terminals *(see Figure 3-7, right)*. It eliminates the hopping of inland vessels from one terminal to another. Inland vessels benefit especially from a common barge terminal, if they are behind schedule [55]. The common barge terminal not only decreases sailing distances for inland vessels in the port, but also creates an additional link in the supply chain [40]. Containers that arrive at the common barge terminal still have to be transported to the terminals *(see Figure 3-7, right)*.

Terminal operators are also interested in a common barge terminal. The common barge terminal handles inland vessels at a dedicated inland vessel quay instead of at a deep sea quay. There is more space and time available to handle sea going vessels. Additional space and time are especially valuable when quay occupancy is high. Terminals have to increase capacity from a certain occupancy rate, in order to meet service time agreements *(see Mooring spaces, page 23).* A common barge terminal can be used as alternative to deep sea quay expansion to create additional quay capacity. Furthermore it can be used to increase the stack capacity by storing empty containers. Inland vessels transport empty containers from the hinterland on a regular basis. Sea going vessels transport in empties only if they a large spare capacity. Empty containers stay longer at the stack than full containers [55].

Also Port of Rotterdam Authority is interested in a common barge terminal. Reduction of the hopping helps to increase the modal split. The creation of additional capacity can postpone empty stack and deep sea quay expansions. Postponing expansions mean cost savings.

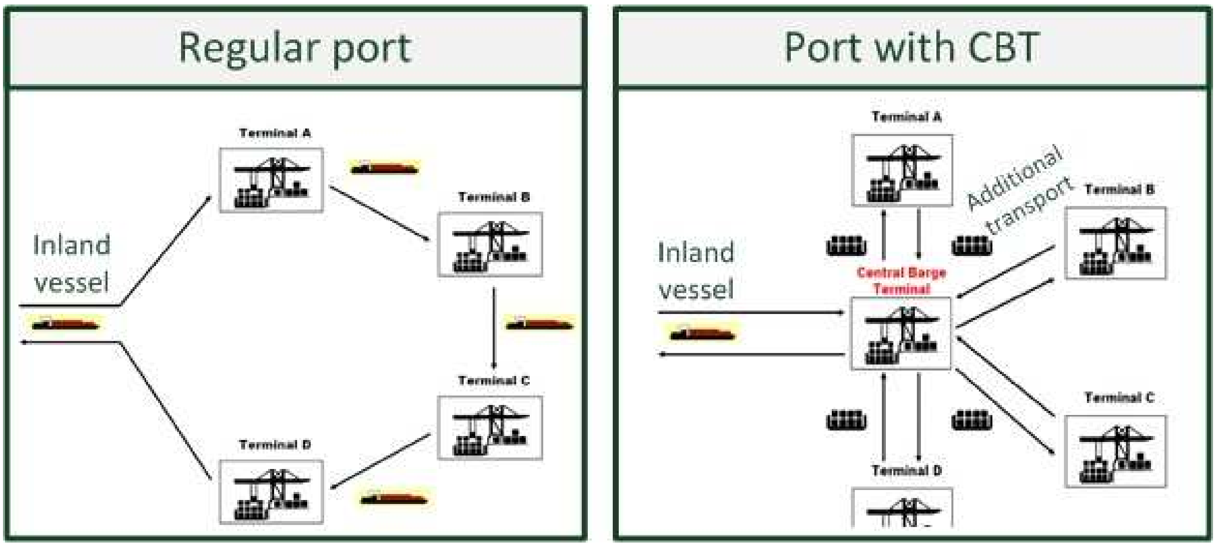


Figure 3-7: A common barge terminal (CBT) reduces the hopping of the inland vessels in the port, but requires additional transport; (left) port without and (right) with CBT [40]

3.2.2 Other activities

Wind energy
Wind turbines emit less CO2 per kilowatt hour and will produce more energy at lower cost in the future than conventional energy forms [8]. Wind energy is attractive along the coast and offshore. The amount of energy produced depends on the wind speed. Larger mean wind speeds will result in far larger amounts of kinetic energy and, even with increasing losses, to far larger amounts of electrical energy. Wind energy also has a downside to the environment. It causes noise, intersects with sailing routes and pollutes the landscape *(see Figure 3-8)*. Wind turbines are allocated on the sea defense of Maasvlakte 1 and will be allocated on the sea defense of Maasvlakte 2. They are less attractive for the inner lake for their payback periods. Most wind turbines are constructed with a concession period of about 20 years [6]. Although operators are obliged to remove all structures again after the concession period, payback periods still amount about 10 years [68]. The average availability of the inner lake amounts seven years [35]. Probably there is not enough time to gain back initial investments. Also other types of energy production are not viable on the inner lake *(see Appendix A.2).*

Figure 3-8: Wind turbines are the most cost effective form of renewable energy in the southern North Sea, their payback periods are longer than the availability of the inner lake [16]

Mussel farming

Mussels have a production cycle of about one year and comprise several stages. Larva's are spread out on the Wadden Sea, fished up as young mussels and further cultivated on banks in the Eastern Scheldt, the Wadden Sea and Lake Grevelingen. The increase in demand has led to more intensive mussel farming. About 3,900 hectares of stable mussel banks, i.e. 98%, disappeared between 1978 and 1997. The Dutch Ministry of Fishery decided to revoke about 2,500 hectares of permits and gave the mussel sector until till 2020 to become a sustainable sector, harvesting with floating instead of bottom techniques [50]. Several mussel farmers have requested the Ministry of Fishery for authorization of mussel farming on the North Sea. Various parasites and a harsh climate require robust facilities. Several ballasted floating structures are tested *(see Figure 3-9)*. Combining floating structures with wind turbines is not feasible [63]. The inner lake has a mild wave climate and could function as temporary solution. Moreover it is closely allocated to mussel farmers in the province of Zeeland. Mussels require easy removable structures and improve water quality by removing silt [50]. Oil spills do not damage mussels as they are located below the water surface. They can make them unsalable, but should not lead to claims to Port of Rotterdam Authority [50].

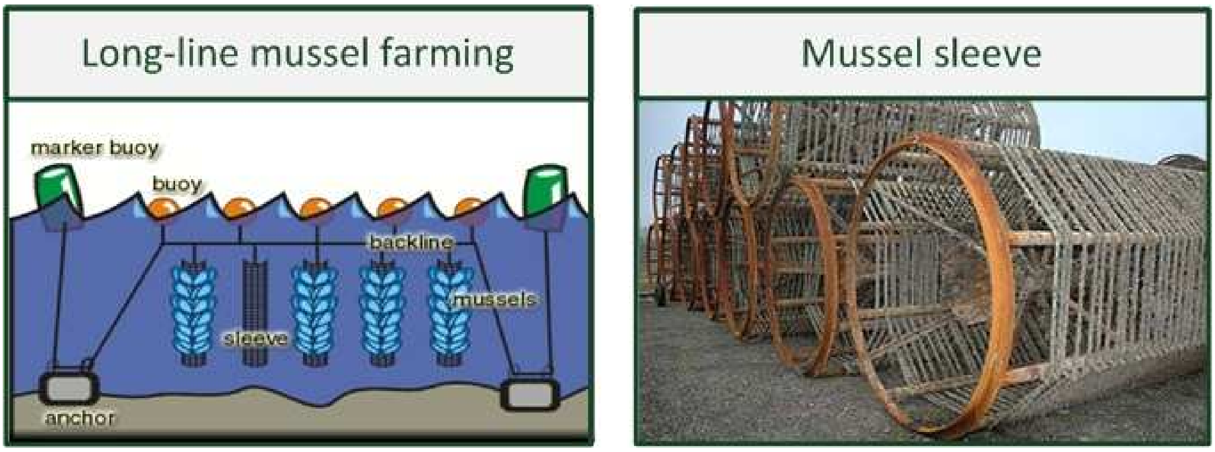


Figure 3-9: The Dutch Ministry of Fishery revoked 2,500 hectares of permits, mussel farmers are testing floating harvesting techniques for the North Sea [13]

Algae farming

Algae are one of the most robust organisms on earth, responsible for about 50% of the photosynthesis and can multiply their weight by six in one day. Algae consist of one-celled plants and multi-celled plants, also referred as seaweeds *(see Figure 3-10, left)* [7]. They can be used in as high quality supplement in food and cosmetics, as fuel, as conditioner in fish farms, as CO2 absorber near power plants and as neutralizer in waste water treatment [20]. A small scale combined algae driven waste water and biogas plant has been constructed some years ago in New Zealand. The plant is unviable, due to its small scale [37]. So far algae only have been beneficial as high quality supplement. They are harvested with labor intensive methods or capital intensive methods, such as rotary cutters. Large scale bio fuel production might be viable on the future [38]. Hortimare has received permission to start with an algae pilot plant offshore *(see Figure 3-10, right)*. A ring shaped system should avoid damage by wind and waves and could be allocated between wind turbines. Layered systems can increase the productivity from 20 to 50 tons (dry matter per hectare per year) [63]. Fish farming is not viable on the inner lake *(see Appendix A.2).*

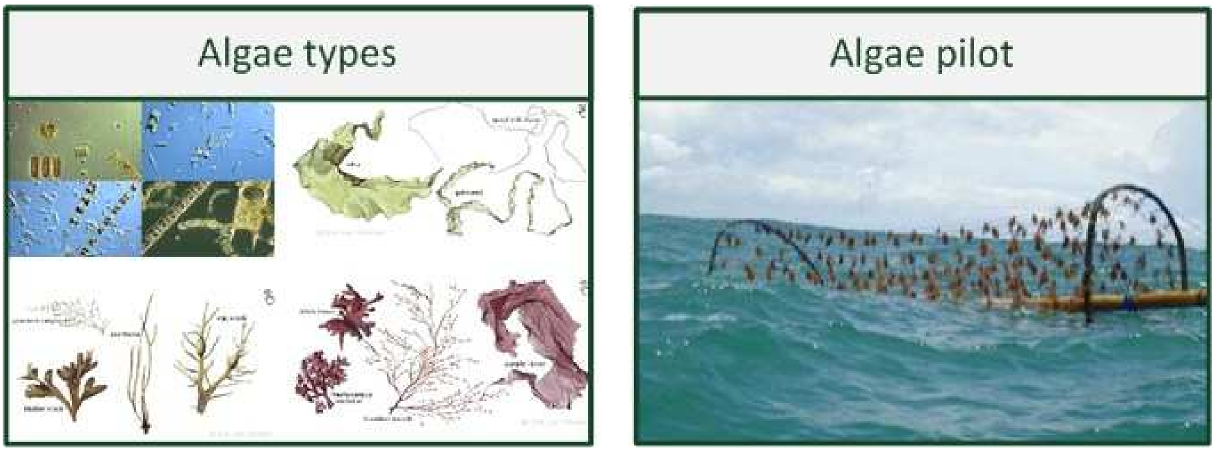


Figure 3-10: Algae are used as high quality supplement and can be used as bio fuel in the future; (left) there are four different algae; one celled-, green-, brown-, red algae and (right) several pilot projects are going on in order to decrease production costs [50]

Hotel at work

The construction of terminals and industrial facilities on Maasvlakte requires many workers. The maximum amount of workers between 2010 and 2035 comprises 2,500 *(see Figure 3-11, left)*. These workers originate often from abroad and have to live as close as possible to their work. Many of them stay in hotel at work on Maasvlakte 1 *(see, Figure 3-11, right)*. Close allocation of the workers to the construction sites minimizes travel times and avoids traffic jams. Any option that reduces traffic on the A15 port motorway is more than welcome. The A15 will undergo major construction works [56]. Hotel at work is allocated on the distribution park at Maasvlakte 1 until 2015. In case no new location is available at Maasvlakte 1, hotel at work can be allocated on the inner lake.

Figure 3-11: Hotel at work houses workers for the construction works of the industrial facilities on Maasvlakte 1 and 2; (left) the expected number of people over time and (right) several guests at the entrance of hotel at work, until 2015 at Maasvlakte 1

Fast ferry

The fast ferry is a line service that sails, with about 40 km/h, from Hoek van Holland to Maasvlakte 1 *(see Figure 3-12, right)*. It is connected at Hoek van Holland with the Dutch national railways and at Maasvlakte 1 with a local bus service that runs via Futureland to Brielle. In 2009, about 53,000 passengers took the ferry, 80% of them were tourists [32]. Most workers travel to Maasvlakte by car, even if travelling times are longer. Moreover industrial sites have plenty of parking lots and do not charge parking fees. Recently, the Municipality of Rotterdam decided to cut their public transport budget. The fast ferry has already been replaced by a slower model and will run less, e.g. only during rush hours, and/or not during winter times. Furthermore the bus service will disappear [32]. Contrariwise Port of Rotterdam Authority considers scaling up public transport. The large amount of commuters to Maasvlakte could decrease traffic safety and induce a gridlock. Separated passenger and freight traffic on Maasvlakte can improve traffic flow. A transfer point at the distripark at Maasvlakte 1 and at Hoek van Holland has to be constructed at which commuters change from private to public transport [56]. From Hoek van Holland commuters could make use of the fast ferry and travel with a bus service to their place of work [56]. Stops at the inner lake are only useful, if enough passengers make a call.

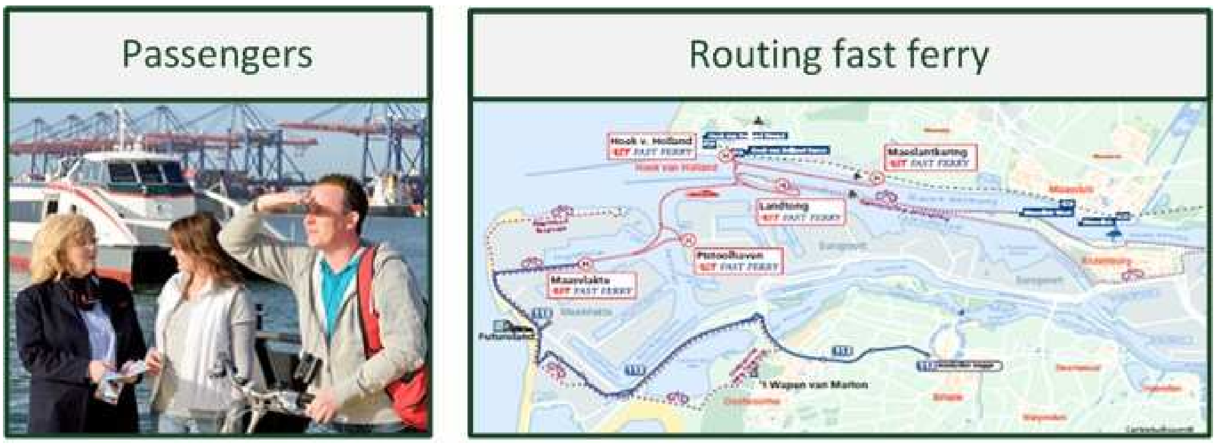


Figure 3-12: The fast ferry runs from Hoek van Holland to Maasvlakte 1, the Municipality of Rotterdam considers scaling down and Port of Rotterdam scaling up; (left) the fast ferry with ticket inspector and passengers and (right) the routing through the port

Nature reserve

The inner lake is an attractive location as nature reserve. The Port of Rotterdam is, together with the Eastern and Western Scheldt, the only fully opened Dutch branch in the southern North Sea. The connection with the North Sea and the Rhine branches lead to brackish water and enables fish to travel up- and downstream. The inner lake can function as acclimatization or spawning area for fish. Its shallow waters enable birds to find food easily *(see Figure 3-13, right).* Due to the attractive site conditions flora and fauna will take place anyhow on the inner lake. The kind of flora and fauna that takes place depends on the other activities. Port of Rotterdam can enhance the flora and fauna development by restricting certain activities. Nowadays nature development is getting more important. The ecological benefits of opening the Haringvliet sluice in the province of Zeeland are verified against the loss of sweet water supplies [50]. An exemption on the flora and fauna regulations promotes temporary use of sites by nature. Developers can proceed with their project, even if protected species come across [22]. Additional territories and food stocks feed on the short term and strengthen flora and fauna on the long term [50]. A temporary nature reserve is not only beneficial for the nature itself, but also to nature fans, such as bird spotters *(see Figure 3-13, left).* They are stakeholders of the Port of Rotterdam Authority and should be well informed about the temporary character [50].

Figure 3-13: A nature reserve on the inner lake increases the food stock, serves as spawning and acclimatization area; (left) birds spotters and (right) birds on the Maasvlakte

Water sports

Sports can be carried out in events, or as leisure [58]. Events can attract a large crowd and last only a certain period. On one hand crowds increase the media coverage of the inner lake and the Port of Rotterdam, on the other hand they require large organizational efforts. The inner lake is located on the edge of the port and not as good connected with infrastructure as other parts of the port. Connections with infrastructure are required to handle large crowds. Even if events take place at the inner lake, they should be scheduled at the initial phase of the inner. Fewer activities on Maasvlakte 2 in the first phase imply a smaller risk. Media coverage is more beneficial for Port of Rotterdam Authority as events are related to the inner lake, the port's vision, its environment and are in line with trends and other events in the port. Possible events are solar, or wind driven boat races. Leisure, such as wind and kite surfing, can be carried on the inner lake throughout the year. The inner lake has a different wave climate than the beach and can be used by beginners *(see Figure 3-14).*

Figure 3-14: Many kind of sports can be carried out at the inner lake, the beach of Maasvlakte 1 was used by; (left) wind - and (right) kite surfers

Dolphinarium

Sea mammal zoos have to inform people about animals in a pleasant way *(see Figure 3-15, left).* They do so by life shows and additional facilities, such as food services and education. Additional facilities enable visitors to set up a varied full day program and are required to attract more visitors from larger distances. The inner lake could function as auxiliary branch for sea mammal zoo in De Koog (NL) or the dolphinarium in Harderwijk (NL). Ecomare in De Koog receives about 300,000 visitors each year and is partly funded by subsidies of the government of 1.5 M€ per year [12]. The dolphinarium in Harderwijk receives about 900,000 visitors and is owned by the private group Compagnie des Alpes. The number of visitors decreased over the years at both zoos. Moreover zoo legislation is strengthened by the awareness about consequences of animals in detention. Stricter rules improved living conditions to animals, but increased operational costs. No new sea mammal zoos have been constructed in Europe in recent years [12]. Furthermore it is questionable whether sea mammals could live well in the Port of Rotterdam. Dolphins communicate, navigate and find food by sounds *(see Figure 3-15, right).* Humans and vessels cause acoustic mist. Motor boats increase the sound level in the Cardigan Bay (UK) from 50 to 85 decibels and made dolphins disappeared in weekends [13].

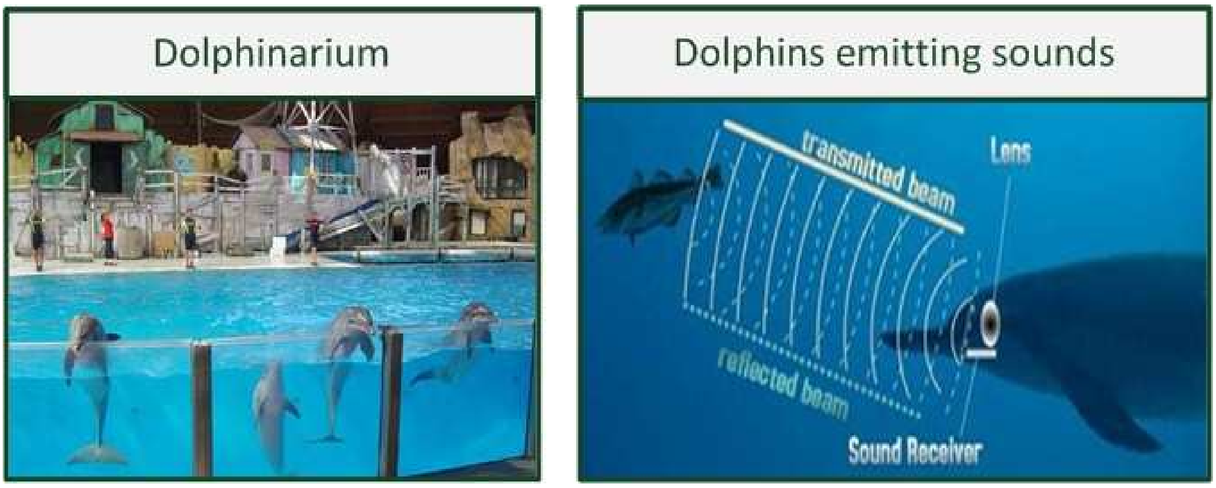


Figure 3-15: (Left) Dolphinarium in Bruges (BE) and (right) dolphins communicate, navigate and find food by emitting sound, humans and vessels cause acoustic mist [13]

3.3 Conclusions

This chapter described potential activities for the inner lake that were collected through a literature study and a brainstorming session. The development plan of Maasvlakte 2 and an internal document on temporary use of the inner lake were consulted to get an insight in the various possibilities. A brainstorming session with people from Port of Rotterdam Authority, Municipality of Rotterdam and Delft University of Technology was carried out to list additional activities and to rank all potential activities using their overall viability as criterion. The feasibility of 14 potential activities was investigated with a literature study and interviews.

Port activities

1) Ship-to-ship transshipment of liquid bulk saves intermediate storage and requires cheaper facilities than ship-to-shore transshipment.
   a) It is especially suitable for unpredictable trading, small and fast growing markets.
   b) Transshipping liquid bulk at the inner lake is more costly for shipping companies than at the North Sea, but safer due to its mild wave conditions and patrol vessels nearby.

2) Granite blocks are transported from Norway to the Benelux.
   a) The contractor quay can be used for storage and transshipment of granite blocks.
   b) The good hinterland connections are an attractive precondition for a facility.

3) Offshore wind turbines are transported in components to ports, assembled in ports and transported to seawards. The market is large. The Port of Rotterdam is attractive.
   a) Until 2030 about 2 wind turbines per day have to be assembled at the North Sea to achieve European Union's renewable energy targets.
   b) A wind turbine assembling facility can benefit from the good hinterland connections and Rotterdam's offshore cluster.

4) Inland vessels have to wait at mooring spaces when a quay is occupied.
   a) Container terminals prioritize sea going vessels, as they have service time agreements and generate more revenues than inland vessels.
   b) A traffic system aims to synchronize arrival times with quay occupancies.
   c) Mooring spaces can be created at the inner lake for inland vessels until the traffic management system is fully operational.

5) Feeders also have to wait, but have a higher priority than inland vessels.

6) A common barge terminal is a neutral transshipment point that enables inland vessels to transship their containers at one location instead of at several terminals.
   a) It eliminates the hopping of inland vessels through the port.
      - Inland vessels can reduce their turnaround time in the Port of Rotterdam.
      - Port of Rotterdam Authority can change modal split in favor of inland shipping.
   b) It creates more space and time at the deep sea quay and in stack.
      - Terminal operators can handle more sea going vessels at the deep sea quay and store more containers in their stack.
      - Terminal operators and Port of Rotterdam Authority can postpone investments in equipment, deep sea quays and empty depots, i.e. save costs.

c) It creates an additional link in the supply chain.
   - Inland vessels transship their containers not at the terminal anymore, but elsewhere. Containers have to be transport to the deep sea quay.

Other activities

7) Wind turbine farms are attractive along the coast. Average wind speeds are high.
   a) However, they cause noise, intersect with sailing routes and pollute the landscape.
   b) Most concession periods lasts 20 years and payback periods at least 10 years.
   c) The average expected availability of the inner lake amounts seven years.

8) Mussel farmers have till 2020 to change from bottom to floating harvesting methods.
   a) The Dutch Ministry of Fishery decided to revoke about 2,500 hectares permits.
   b) Floating ballasted structures are not feasible in harsh North Sea conditions yet.
   c) The inner lake has a mild wave climate and could function as temporary solution.

9) Many small scale pilot projects are carried out with algae at the moment. Algae are:
   a) Financially viable as high quality supplement in food and cosmetics.
   b) Not financially viable as fuel, as conditioner in fish farms, as CO2 absorber near power plants or as neutralizer in waste water treatment.

10) Hotel at work houses workers of construction projects on Maasvlakte 1 and 2.
   a) Most of the 2,500 workers come from abroad. They have to stay as close as possible to their place of work to minimize traffic jams.
   b) Hotel at work is allocated at Maasvlakte 1 at the moment. It can be relocated to the inner lake as floatel from 2015.

11) The fast ferry is a line service that sails from Hoek van Holland to Maasvlakte 1.
   a) Commuters prefers private over public transport, 80% of the travellers are tourists.
   b) The Municipality of Rotterdam decided to cut the public transport budget; reduce the frequency of the fast ferry and cancel the related bus line.
   c) Port of Rotterdam Authority considers scaling up public transport to Maasvlakte 1 and 2 to increase traffic safety and avoid a grid lock.

12) Nature will develop on the inner lake anyhow due to its attractive site conditions.
   a) The inner lake can function as acclimatization, spawning area or food stock.
   b) Temporary nature is nowadays rather seen as helping than harming flora and fauna.
   c) New regulations on temporary nature avoid hindrance to the port development.

13) Sports can be carried out in events, or as leisure.
   a) Events can attract large crowds, require infrastructure, safety measurements and are more beneficial if they have relation with the port, e.g. wind driven boat races.
   b) Leisure can be carried out throughout the year by kite and wind surfers and is attractive because the inner lake has another wave climate than the beach.

14) Dophinarium has to inform people about sea mammals in a pleasant way.
   a) The number of visitors decreased over the years at the sea mammal zoos.
   b) Stricter rules improved living conditions to animals, but increased operational costs.
   c) Humans and vessels cause acoustic mist to dolphins that communicate via sounds.

4 Potential port infrastructures

This chapter describes potential structures that enable activities to take place on the inner lake. Section 4.1 illustrates the literature used to collect potential structures. Section 4.2 describes the structural principle and construction methods.

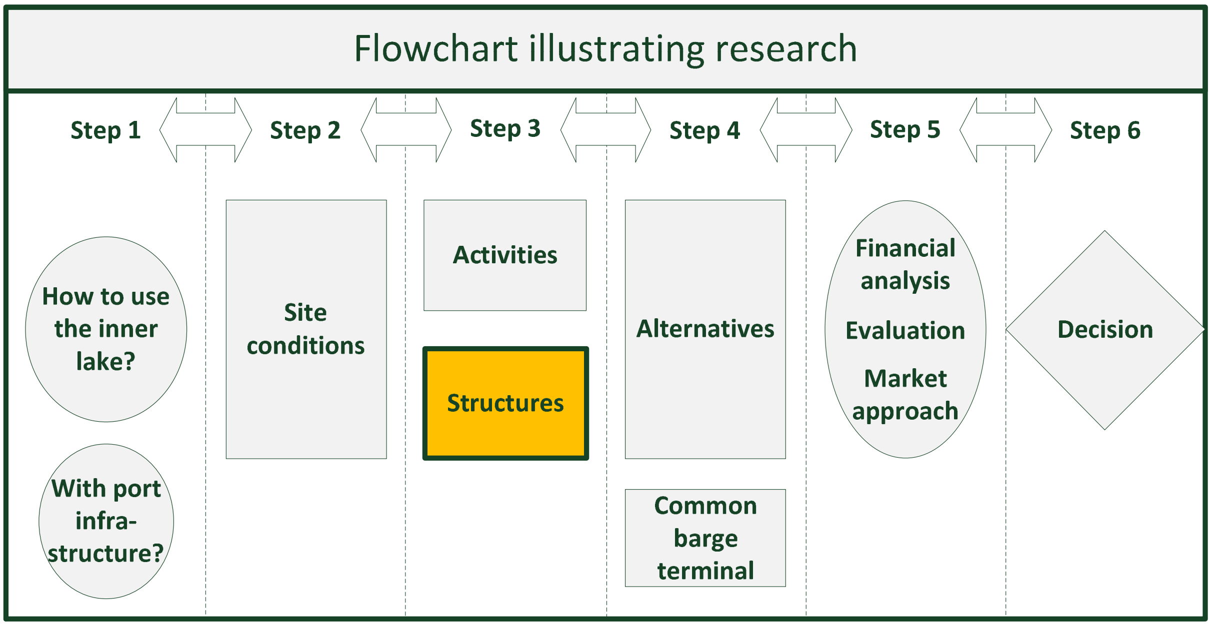


Figure 4-1: Flowchart illustrating research, chapter 4; description of structural principle and construction method of quays that are coupled with some activities to alternatives

4.1 Inventory of potential structures

Port infrastructure comprises all structures that facilitate port activities and can be divided into basic infrastructure, equipment and superstructures. Basic infrastructure comprises channels, quays and roads. Superstructures comprise parking areas, fenders bollards. Equipment comprises cranes and forklift trucks [33]. This chapter describes the basic infrastructure that enables transshipment and storage of cargo. Quays are part of the port infrastructure and require additional features before they can be used.

Structures have to be constructed in compliance with the site conditions. The sites of the inner lake have an average water depth of 15 m. They can be used for about 7 years and have to be returned without any remaining structural parts. Most structures have a technical lifetime of about 50 years [33]. Structures on the inner lake have to be adapted to the phased development of Maasvlakte 2. Only single use or flexible multiple use structures can do so. Single use structures have a technical lifetime that equals the service time. Flexible multiple use structures have a technical lifetime that is several times longer than the service time and can be relocated. Potential single and multiple use structures are described in several references.

Port of Rotterdam Authority has called in 1998 in an open competition for cheap, flexible and sustainable structural concepts for the Port of Rotterdam. Reusable caissons, Maxisteck and Containerland seemed promising and have been elaborated to preliminary designs. Finally, Containerland has been constructed as pilot [45].

From 1998 onwards several other concepts have been developed. Some ports are only accessible through shallow water and cannot welcome all ship sizes anymore. Other ports are searching for solutions to speed up (un)loading processes. Floating structures can relocate port activities to deeper waters and accelerate transshipments. They are several times more expensive than bottom founded structures [19], but much more flexible. Most literature mentions very large floating structures and barge type structures.

Although many new or retro concepts have been developed, also conventional port structures might fit the site conditions of the inner lake. Common port structures are sheet pile walls and L walls.

Structures transfer loads in a different way *(see Figure 4-2)*. Bottom founded structures transfer loads to the subsoil. A sheet pile wall and Maxisteck transfer forces through an upper soil layer to a deeper soil layer. They are deeply embedded into the subsoil. An L wall, caisson and Containerland transfer all loads to the upper soil layers. They are not or only some meters embedded into the sub soil. Floating structures transfer loads to the water. A very large floating structure and a barge use buoyancy to balance out vertical forces. Horizontal forces are balanced out by a mooring system. The structures are described more in detail further along this chapter.

Figure 4-2: An open competition in 1998 collected Containerland, Maxisteck and a reusable caisson, from 1998 several references describe a very large floating structure and barge type structure, a sheet pile wall and L wall also might fit to the site conditions

4.2 Description of potential structures

Sheet pile wall
A sheet pile wall is a retaining structure that is driven into the subsoil. The subsoil exercises forces on the sheet pile through active and passive pressures. Whereas active soil pressures tend to displace the sheet pile, passive soil pressures tend retain the sheet pile.

Larger retaining forces are obtained by driving longer sheet piles deeper into the subsoil, by decreasing excess active soil pressures through drainage, or by placing anchors at the top of the sheet pile. Mostly, these three methods are combined.

Anchors derive their retaining force from passive soil pressures out of the area of influence of the active soil pressures. There are many different types of anchors available, for example horizontal anchors, grout bodies and tensions piles. Horizontal anchors with vertical steel plates can be quite easily installed and demobilized. They are appropriate for the site conditions of the inner lake. Sheet piles are fixated at the bottom by filter layers and stone structures to avoid erosion, connected to each other by interlocks and connected to a girder at the top [33].

Sheet pile walls are usually constructed in situ. Firstly, the site is leveled with a regular grab and the sheet piles are transported to the site. Subsequently, the sheet piles are driven into the subsoil. Finally, the subsoil on the water side is excavated, the bottom protection is placed, supra structures and infra plus structures are constructed *(see Figure 4-3)*. Sheet pile walls have a relative low weight, resulting in small long term settlements, and are suitable for sites with poor bearing capacities and good penetration characteristics [33].

Figure 4-3: Construction of sheet pile walls (clockwise); (top left) leveling of the site with grab, (top right) stock of sheet piles, (bottom left) drive sheet pile into subsoil, (bottom right) excavate subsoil

Maxisteck

Maxisteck is an open berth structure that consists of a platform supported by piles. The platform consists of a steel frame, a prefabricated concrete deck and an in situ concrete deck. Whereas the prefabricated steel frame and concrete deck transfers the load to the piles and subsoil, the in situ concrete deck stabilizes Maxisteck to a monolithic structure [34].

The Maxisteck concept is derived from offshore industry and has short assembling times. Firstly, piles are driven into the subsoil. Meanwhile the steel frame and prefabricated concrete deck are constructed and transported to the site with floating heavy lifting equipment. Subsequently, the frame and deck are lifted onto the piles *(see Figure 4-4).*

Lighter lifting equipment can be used, if the frame and deck are lifted separately. The steel frame is connected to the piles and the concrete deck with neoprene supports to enhance the equal spread of the loads over the structure. Maxisteck allocates a minimum amount of structural elements under the water level and is suitable for sites with a very low bearing capacities, or protected slopes [34]. Maxisteck never has been constructed so far. A Maxisteck-like structure has been constructed in Nagoya, Japan.

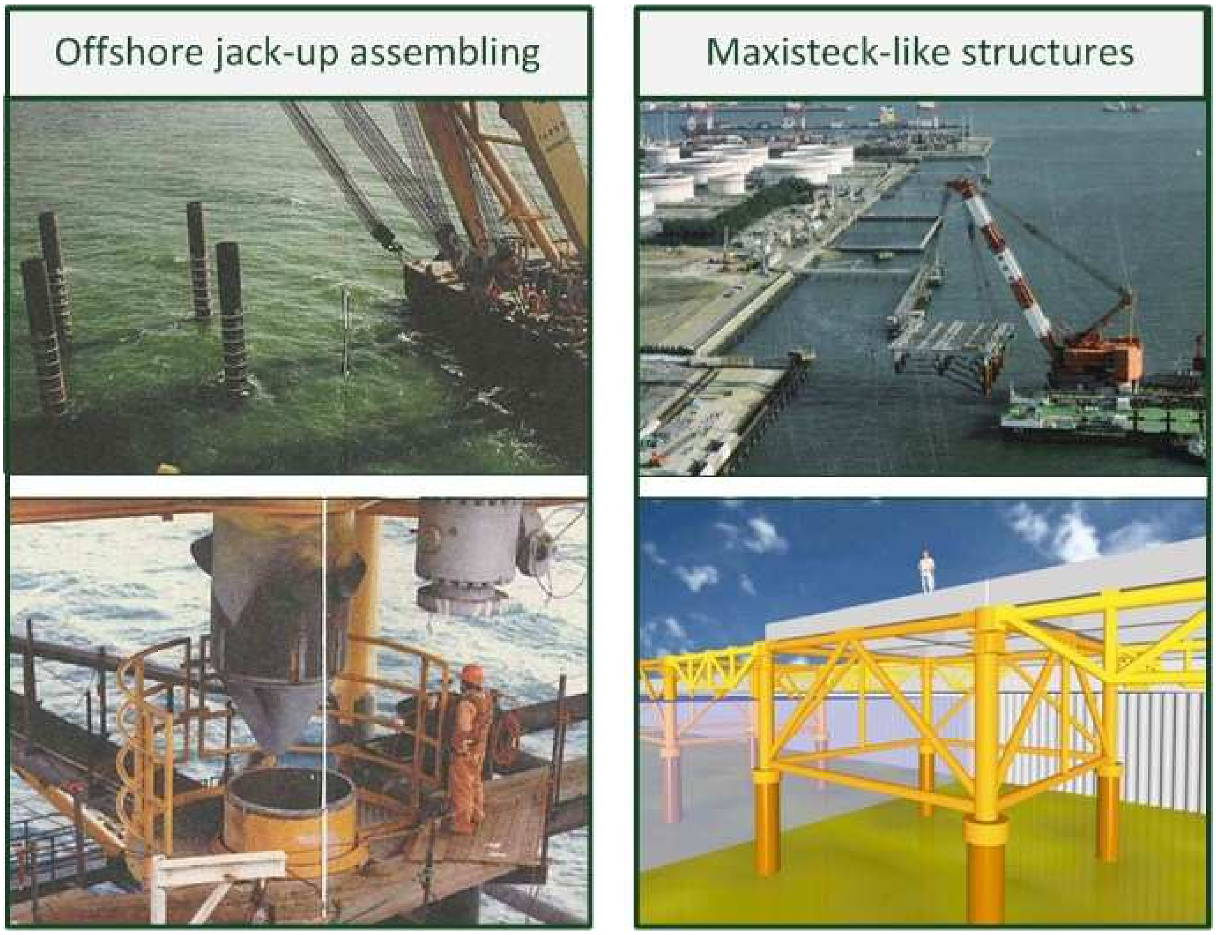


Figure 4-4: Illustration of how a construction of Maxisteck cound be (clockwise); (top left) drive piles into subsoil, (top right) transport frame to site, (bottom left) place frame on piles, (bottom right) final situation

L wall

An L wall is a gravity based structure that is allocated on the subsoil. Passive subsoil forces bear the L wall. Active subsoil forces tend to displace and overturn the L wall. A horizontal displacement is avoided by larger weights creating larger shear forces. Overturning is avoided by larger weights further away from the retaining wall. Larger weights not only evoke larger counteracting moments, but also tensile forces. Reinforcement absorbs tensile forces, enables to construct slimmer structures, reduces volume and save material costs. L walls are founded on filter layers and stones to distribute the weight and to avoid erosion [33].

L walls can be constructed in situ or prefabricated elsewhere. Small numbers are usually constructed in situ. Large numbers are usually prefabricated. Firstly, the site is leveled with dredgers and the bottom protection is constructed. Then L walls are constructed with formworks and, in case of prefabrication, transported to the construction site. Transport of L walls requires heavy lift equipment *(see Figure 4-5)*. Finally, the subsoil deposited on the L wall and supra structures and infra plus structures are constructed. L walls are usually suitable for sites that have moderate penetration characteristics [33].

Figure 4-5: Construction of L walls (clockwise); (top left) construction L wall with formworks, (top right) placing, (bottom left) stocking before transport, (bottom right) placed on site

Caisson
A caisson is a gravity based structure that consists of large hollow elements. It exercises forces on the subsoil by its own weight and its ballast. Ballast consists of water or sand and avoids horizontal, vertical displacements and overturning. Caissons can be constructed in situ or prefabricated elsewhere and transported to the site *(see Figure 4-6).* Prefabricated caissons can be constructed in a dock, transported with tugs and sunk onto the subsoil. Furthermore they can be constructed on a regular construction site, transported with (floating) heavy lift equipment and lifted onto the subsoil [33].

The prefabrication method is determined by the availability of sites, equipment, the dimensions of the transport route, the weather conditions and contractor's experience. Whereas tugs are usually more cost effective, heavy lift equipment is less dependent on weather and can displace caisson with ballast [33].

Before caissons are founded onto the subsoil, weak layers have to be replaced by filter layers and stones. Then, caissons are filled with ballast, sunk onto the subsoil and connected to each other with rubber profiles. Finally, the supra structures and infra plus structures are constructed. Caissons can be reused by removing the ballast with pumps and floating the structure to another location, or lifting the structure and ship the structure to another location. Prefabrication of caissons is only financially attractive for larger numbers [33].

Figure 4-6: Construction of caissons (clockwise); (top left) prefabrication on site, (top middle) placing with crane, (bottom left) prefabrication in dock, (bottom middle) transport with tug, (right) at final location

Containerland

Containerland is a gravity based single use structure that consists of a package of containers sandwiched between two concrete slabs. Containers are usually stacked on each other in several layers (15 m). The corner pillars of a container transfer the weight of the upper containers to the lower containers or subsoil. The walls of a container ensure the stability and transfer only a small amount of the upper weight. Concrete slabs redistribute the pressures from the surface to corner pillars and from the corner pillars to the subsoil. Top layers and filter layers redistribute the pressures even further and avoid unequal settlements [45].

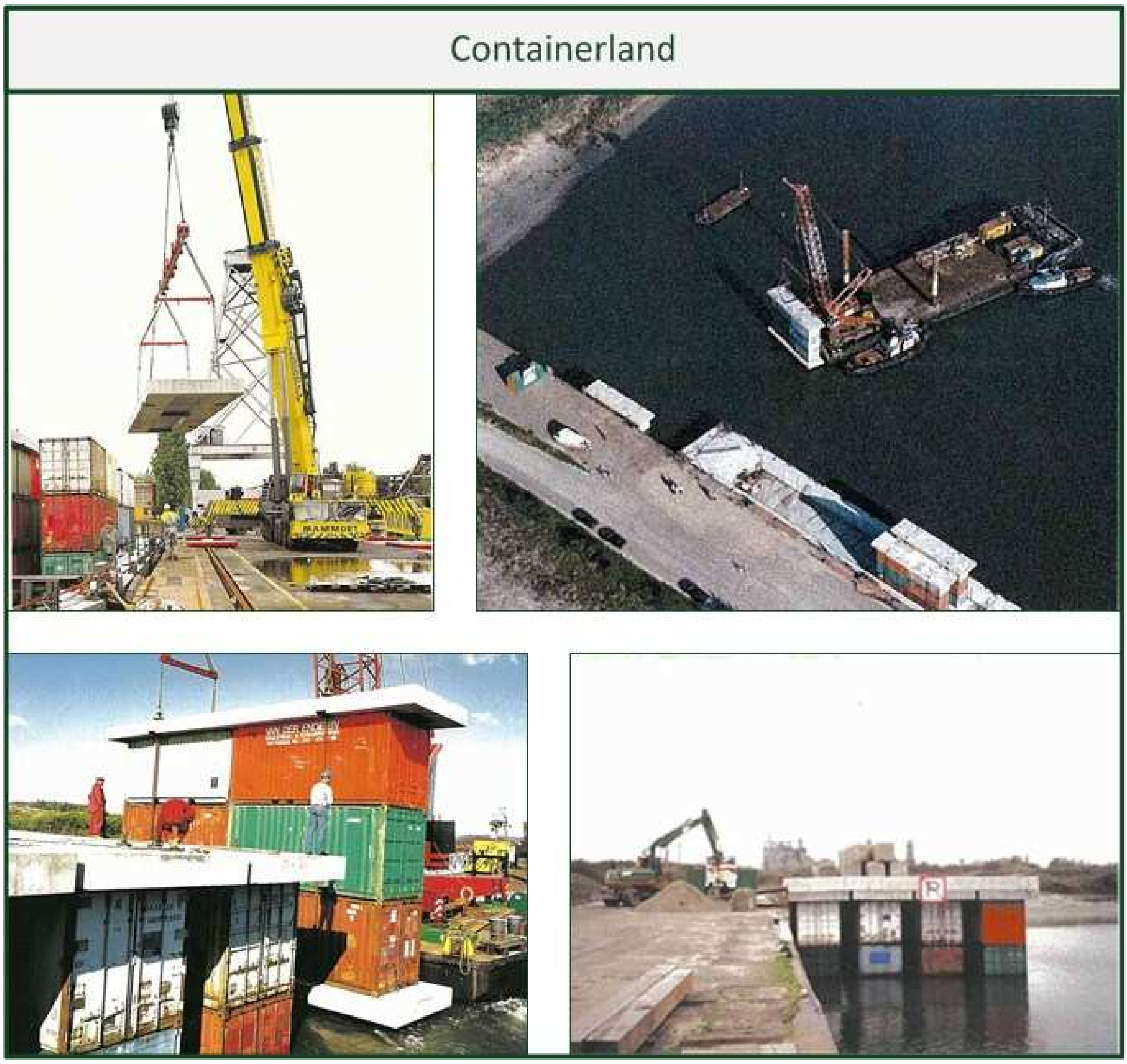


Figure 4-7: Construction of Containerland (clockwise); (top left) assembling, (top right) transportation, (bottom left) assembling, (bottom right) final situation

While Containerland can withstand considerable vertical forces (40 kN/m2), its capacities to withstand horizontal forces are limited (vessels of 5,000 DWT). The walls and girders are not designed to withstand large forces. In order to absorb mooring forces better, Containerland has to be allocated with its short side to the waterfront. Furthermore it has to be connected to the shore by platforms, bridges or floating structures [17].

Containerland can be constructed with new and second-hand containers. They are suitable as long as the frame is straight and strong enough. The technical lifetime of containers in seawater is about 5 years. The technical lifetime can be extended with cathodic protection to about 10 years [17]. Containers are made permeable, to enable ballast water to enter, sandwiched between two concrete slabs and connected to each other and the slabs with hawsers to packages. Packages are transported and placed on the leveled subsoil with floating lifting equipment *(see Figure 4-7).* Finally, Containerland is covered with a top layer and provided with supra structures [45].

Very large floating structure

Floating structures transfer loads to the water and a mooring system. The working loads and wave loads translate and rotate the floating structure. Translations and rotations of the structure decrease the workability and make connections to other floating structures and the shore difficult. Translation and rotations can be reduced by the shape of the structure and mooring systems. The shape of the structure usually cancels out first order wave loads, by adapting the natural frequency to the excitation wave frequency. Mooring systems usually cancel out higher order wave loads, by external forces, such as chain/wire moorings, tugs, or dynamic positioning systems [1].

A very large floating structure is a concrete box shaped structure with large dimensions. The structure consists of several pre stressed-concrete modules. The modules can be allocated in a rectilinear, shifted or jigsaw pattern and are connected to each other by tendons. The very large floating structure is fixated by mooring dolphins and constructed, just as caissons, in large docks. So far, very large floating structures have been constructed as airstrip and storage for liquid bulk *(see Figure 4-8)* [1].

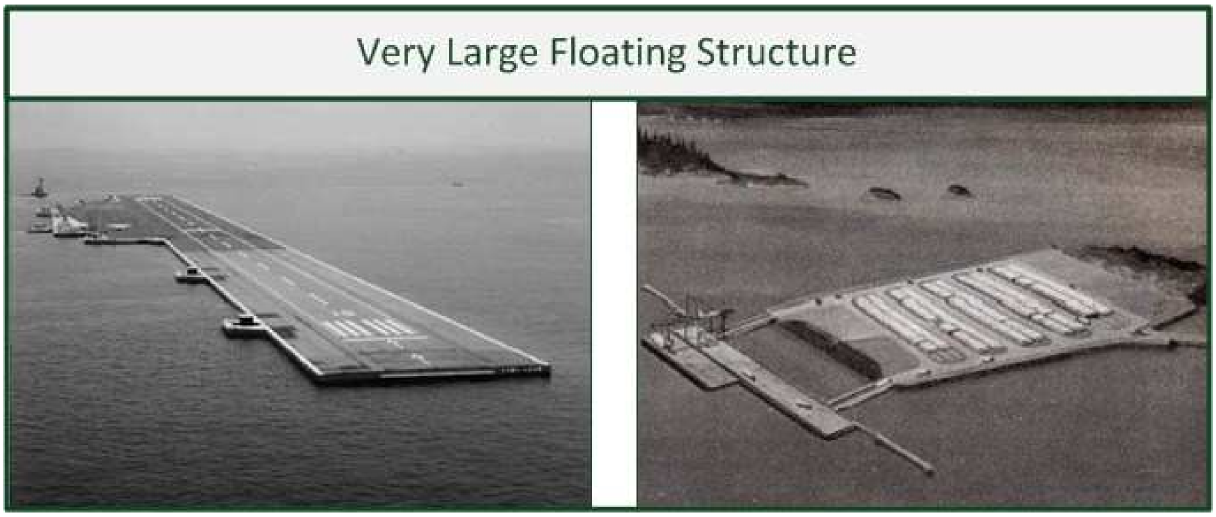


Figure 4-8: Examples of very large floating structures; (left) floating airstrip, Tokio, Japan and (right) floating storage, Valdez, Alaska

Barge

A barge is a steel structure that serves dedicated operations. The structure displaces itself by its own propulsion system and keeps position with thrusters, mooring lines, or tugs. A barge is usually constructed for ship to ship transshipment and equipped with cranes, or other self-(un)loading systems [1]. Barges are already in operation for commodities that are transshipped in remote areas.

Small oil- and gas fields are extracted by FPSO (Floating Production Storage Offloading vessels) and remote coal areas are made accessible by Floating Transfer Stations. So far, the Port of Ponce has signed a letter of intent for the Korea Advanced Institute of Science and Technology for floating container terminal *(see Figure 4-9).*

Figure 4-9: Examples of dedicated barges; (left) Floating Transfer Stations Bulk Wayuu, Venezuela and (right) demonstration Korea Advance Institute of Science and Technology mobile harbor

4.3 Conclusions

This chapter described seven structures. Port of Rotterdam Authority assessed a reusable caisson, Containerland and Maxisteck in an open competition as potential cheap, flexible and sustainable structural concepts. Many ports consider floating structures to redress their accessibility to large vessels and accelerate transshipments. Also a sheet pile wall and L wall might fit the site conditions of the inner lake. Structures can transfer loads (deeply) to the subsoil or water. They can be prefabricated or constructed in situ:

1) A sheet pile wall is a retaining structure that is driven into the subsoil.
   a) Active soil pressure tend displace and passive soil pressures tend to retain.
   b) Larger retaining forces are achieved by longer sheet piles, drainage and anchors.
   c) A sheet pile wall is constructed in situ with sheet pile driver and grab.
   d) Sheet piles are suitable for sites with poor bearing capacities.

2) Maxisteck consists of a concrete deck and steel frame are placed on piles.
   a) The prefabricated frame and deck transfer loads via piles to the subsoil.
   b) The in situ concrete deck stabilizes Maxisteck to monolithic structure.
   c) Frame and deck are placed with floating heavy lift equipment on piles.
   d) Maxisteck allocates a minimum amount of structural elements under the water level.

3) An L wall is a concrete structure with soil on top of it.
   a) Active soil pressures tend to displace and overturn the L wall.
   b) Larger weights (from the center of gravity) avoid displacements and rotations.
   c) Small numbers are constructed in situ. Large numbers are prefabricated.
   d) L walls are suitable for sites that have moderate penetration characteristics

4) A caisson is a concrete structure that consists of hollow elements.
   a) Structure’s weight and ballast (water or sand) avoid displacements and rotations.
   b) Prefabricated caissons are constructed in a dock, transported with tugs and sunk onto the subsoil or transported with heavy lift equipment and lifted onto the subsoil
   c) The method depends on the sites, equipment, route, weather and experience.
   d) Removing is possible by pumping out ballast, or lifting the entire caisson.

5) Containerland consists of containers sandwiched between two concrete slabs.
   a) Concrete slabs redistribute the pressures, corner pillars transfer loads to the subsoil.
   b) Walls ensure the stability, other structures or ballast has to absorb horizontal forces.
   c) Container’s lifetime in seawater is about 5 years, with cathodic protection 10 years.
   d) Packages are assembled, transported and placed with floating lifting equipment

6) A very large floating structure consists of several prestressed-concrete modules.
   a) Floating structures use buoyancy and mooring systems to transfer forces.
   b) Modules are connected with tendons in a rectilinear, shifted or jigsaw pattern.

7) A barge is a monolithic floating steel structure that serves dedicated operations.
   a) Translation and rotations can be reduced by the shape and mooring systems.
   b) The shape of the barge is used cancels out the first order wave forces.
   c) The mooring systems (chain/wires, thrusters, tugs) and barge’s propulsion are used cancel out higher order wave forces and displace the structure.

5 Alternatives for the inner lake

This chapter describes where activities could take place on the temporary inner lake and which structures they require. Section 5.1 groups the activities by their requirements. Based on these requirements, the activities are allocated on the inner lake and combined with structures to alternatives.

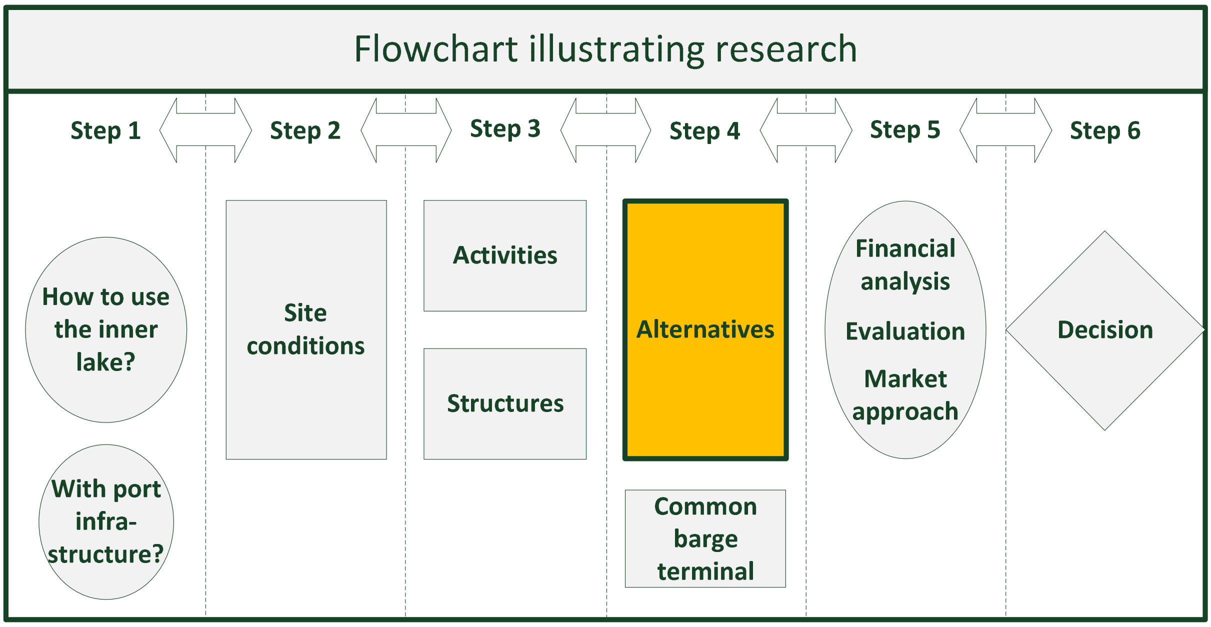


Figure 5-1: Flowchart illustrating research, chapter 5; coupling of activities with structures to alternatives and allocation on the inner lake by functional requirements

5.1 Functional analysis

Requirements allocate the activities on the inner lake and combine the activities to structures. Activities are grouped by common requirements *(see Figure 5-2).*

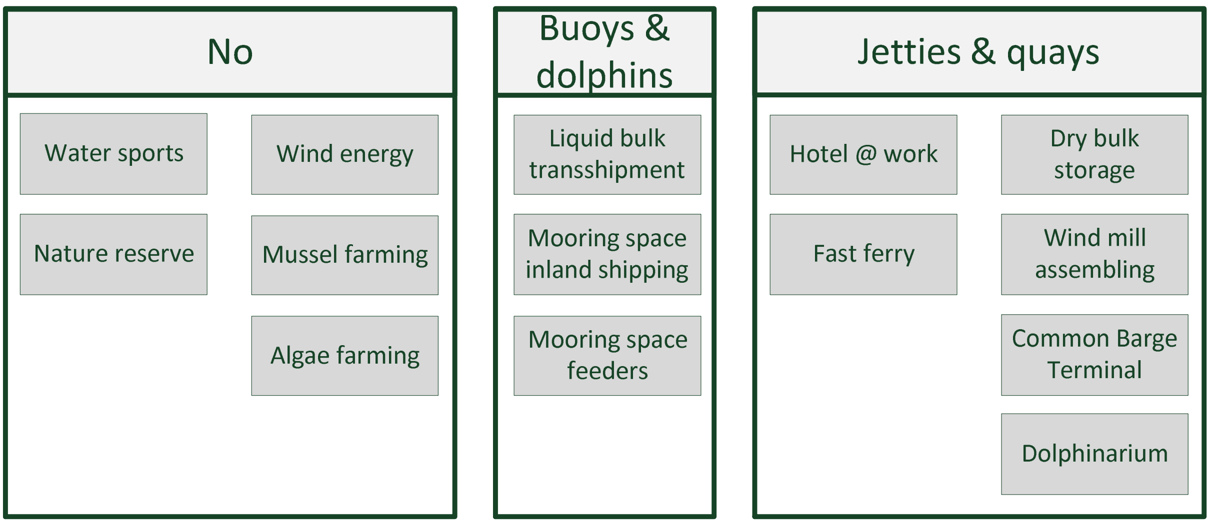


Figure 5-2: Activities grouped by requirements; activities that require (left) no facilities by Port of Rotterdam Authority, (middle) mooring facilities and (right) jetties or quays

Requirements ensure that activities can fulfill their need and the consequences to the environment are limited. Some activities require waterside-, or landside access, other have to be allocated at a certain distance away from the environment for safety reasons for example. Some activities require a mooring structure, jetty, or quay, other do not require any facility. The extent of the activities determines the dimensions of the facilities *(see Appendix B.1).*

5.1.1 No structures

Water sports
The inner lake can be used completely by water sports. They usually want to achieve high speeds and can capture a large part of the coastal zone. However, large velocities and unpredictable weather conditions can easily take sportsmen off track, into the Yantzehaven or Arianehaven, and endanger nautical safety. Therefore only the closed part of the inner lake can be allocated to water sports. Moreover water sports cause noise and give nature fewer chances to develop *(see Figure 5-3).* Sport equipment is usually transported over the road to the shore. Therefore water sport areas require roads and parking areas. Parking areas are available at the sea defense. Port of Rotterdam Authority can decide to construct temporarily some more.

Nature reserve
In case no activity is allocated on the inner lake nature develops. The kind of flora and fauna that develops and its development speed depends on the other activities at the inner lake and their distances. Flora and fauna has fewer changes adjacent to port activities and should be allocated in the closed part of the inner lake *(see Figure 5-3).* Still some species will develop in the open part. They will attract other species and increase the biodiversity, comprising protected species and threaten the development of Maasvlakte 2.

Wind energy
Wind farms are allocated offshore and at coastal areas due to high local average wind velocities. They comprise several wind turbines and cover large areas. Several wind turbines make use of the same cable that connects the wind farm to the grid and decrease the investment cost per turbine. Wind turbines are an obstacle for the air flow and cause wake effects, decreasing the energy extraction capability for a distance of 5 to 6 times the rotor diameter. Regular offshore wind turbines have a rotor diameter of about 100 m and require a center to center distance of about 500 m [44]. This implies that about 20 wind turbines can be allocated at the inner lake. Wind turbines have to be maintained and be accessible by boat or by road for maintenance engineers and could be allocated all over the inner lake. They form, however, an obstacle to water sports, nature development *(see Figure 5-3).*

Mussel farming
Mussel larva's attach themselves to sleeves and eat nutrition carried along with the tide. Less nutrition is carried into the closed part than into the open part *(see Figure 5-3).* The tide not only carries less nutrition, but also less pollution into the closed part. Oil spills occur rarely and rather on a small scale, but could make mussels unsalable. Mussel sleeves are installed, harvested and demobilized with small fisher boats. In case the opening in the dike is large enough larger fisher boats and more nutrition enters the closed part of the inner lake. Mussel farmers can produce about 10 tons per hectare per year [50].

Algae farming

Algae grow by photosynthesis and grow faster with more sunlight, water and CO2 [7]. Layered systems capture the sunlight more efficient. Wide shallow channels with plastic at the bottom capture more sunlight in the top layer. Covered systems, as glasshouses, can keep added CO2 from power plants. Connections to power plants are too expensive at the moment [51]. Small density pilot projects are feasible, should not be exposed to oil spills. They could take place in the closed part of the inner lake *(see Figure 5-3).*

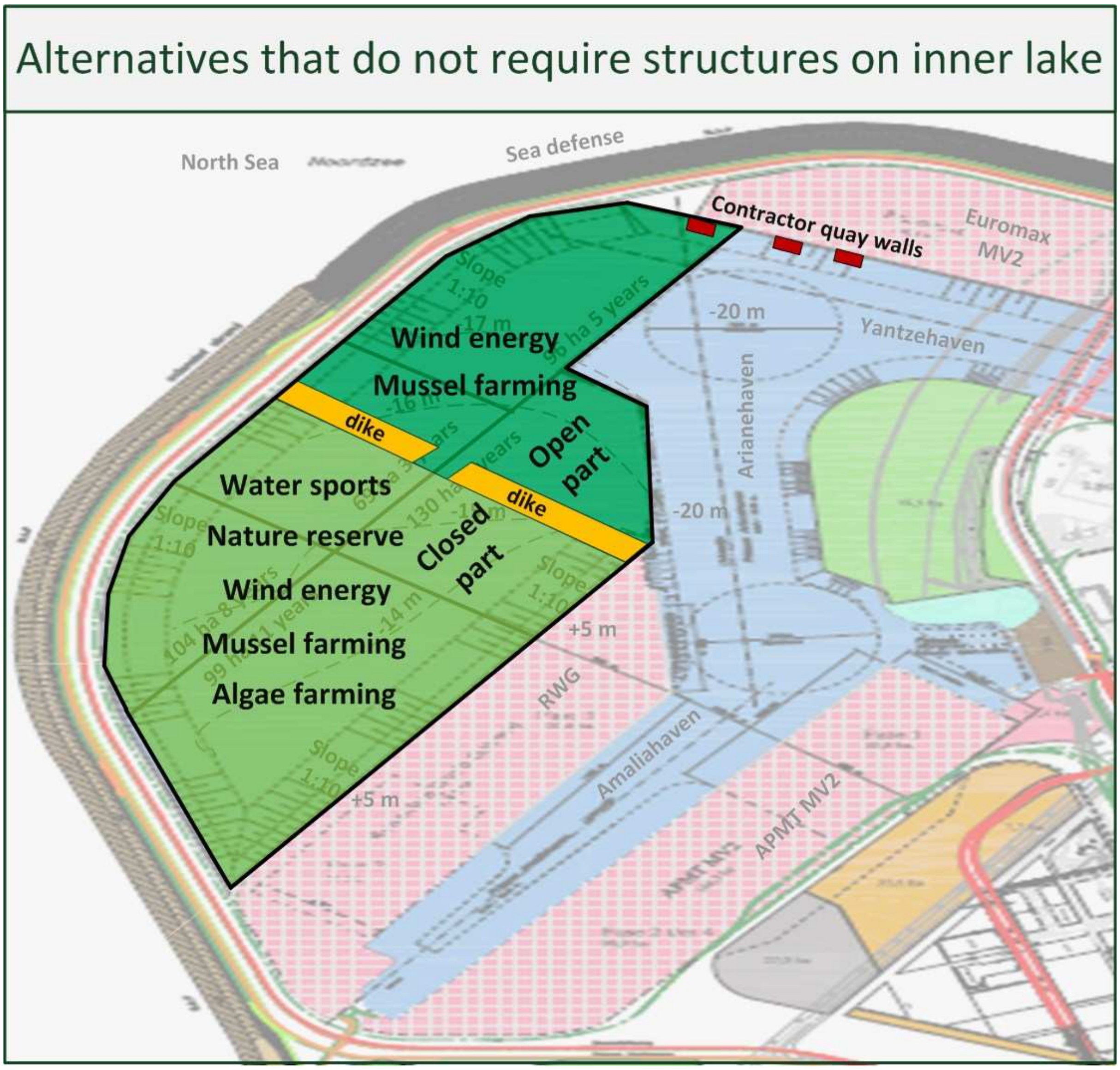


Figure 5-3: Allocation of activities on the inner lake that require no facilities; connected with the Yantzehaven and Ariannehaven (open part), partially separated from the port by a dike (closed part)

5.1.2 Buoys and dolphins

Liquid bulk transshipment

Vessels that transship liquid bulk are moored with tugs and ball shaped fenders. Furthermore they are moored by their own anchorage and additional mooring lines. The liquid bulk is transshipped from the central manifold of one vessel via flexible hoses to the central manifold of the other vessel. The transfers comply with regulation of the Oil Companies International Marine Forum and are under continuous supervision, enabling to restrict and report accidents quickly [39]. Most accidents concern small oil spillages and can be absorbed by 100 m long screens of the patrol vessels. Larger oil spillages can be absorbed by 300 m long screens, stored in the port in containers at strategic locations. Attachment points at the banks enlarge the capture area and fixate the screens even better [52].

The inner lake has a maximum water depth of 17 m which allows only vessels with a smaller draft to transship their cargo *(see Figure 5-3).* Suezmax vessels have a DWT from 120,000 to 200,000, a LOA of about 400 m, a width of about 45 m and a draft of about 16 m. A ship-to-ship transshipment carried out with two Suezmax vessels require an area of 400 times 100 m. Dredging the Amaliahaven to its final depth at – 20 m NAP in the open part of the inner lake will enable VLCCs to transship their cargo as well. VLCCs transship their cargo rarely from ship-to-ship. Their facility in the Calandkanaal has a low occupancy rate [49]. The ship-to-ship facilities in the Calandkanaal consist of several mooring and berthing piles. Tidal flow velocities and adjacent navigation channels require about one mooring and berthing pile per 50,000 DWT [49]. The inner lake has lower tidal flow velocities, enables to allocate ship-to-ship locations further away from navigation channels and requires less mooring facilities.

Mooring space inland shipping and feeders

Safe and efficient shipping is enhanced by mooring spaces. Inland vessels have a maximum DWT of about 3,000, a LOA of about 135 m, a width of about 10 m and a draft of about 5 m (CEMT-classes). Feeders have a maximum DWT of about 16,000 DWT, a LOA of about 170 m, a width of about 30 and a draft of about 10 m (Unifeeder fleet list). Although nowadays more and more inland vessels are equipped with spud piles [55], they still require mooring facilities. A close allocation of the mooring facilities to the channels and terminals minimizes sailing times *(see Figure 5-3).*

Buoys and dolphins

Mooring structures have to absorb berthing and drift forces. The choice of a mooring structure depends on the site conditions, vessels and their aspired unloading rates:

- Buoys are floating structures founded by several chains with anchorages or pile foundations to the bed *(see Figure 5-4*). They are displaced by drift forces. Displacements decrease (un)loading rates, increase the probability of spillages and require safety distances to critical water depths and fire sources. Multiple and single buoy systems exist. A single buoy mooring enables a vessel to take the most favorable position to the drift forces. This system is constructed for one vessel and is not suitable for direct ship-to-ship transshipments [25]. A multiple buoy system has to be used.
- Dolphin structures split the berthing and mooring functions into berthing and mooring piles *(see Figure 5-4*). Berthing dolphins absorb berthing forces via fenders. Mooring dolphins absorb drift forces via mooring lines and hawsers. Dolphin structures are constructed for specific vessel classes and only allow a small variation of vessel sizes.

The vessel's DWT determines the amount of buoys or dolphins required. Whereas buoys are cheaper, dolphins ensure smaller displacements and allow larger (un)loading rates. For throughputs of several million tons per year and small variations in call sizes dolphin structures are more economical than buoys [25].

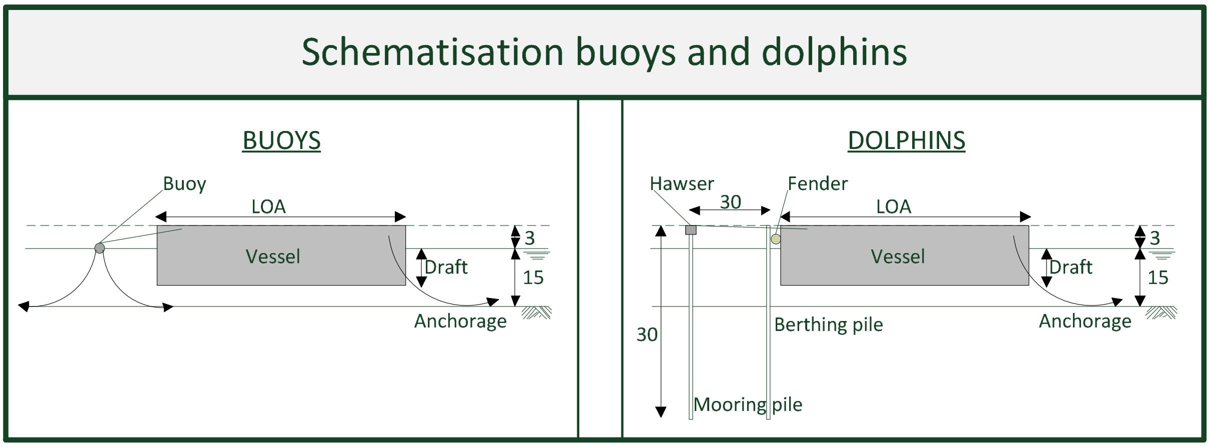


Figure 5-4: Mooring structures side view (not on scale); (left) buoy fixed to bed by anchors, larger displacements, but also lower investment costs, (right) dolphin distributes berthing and mooring functions to two separate piles *(dimensions see Appendix B.1)*

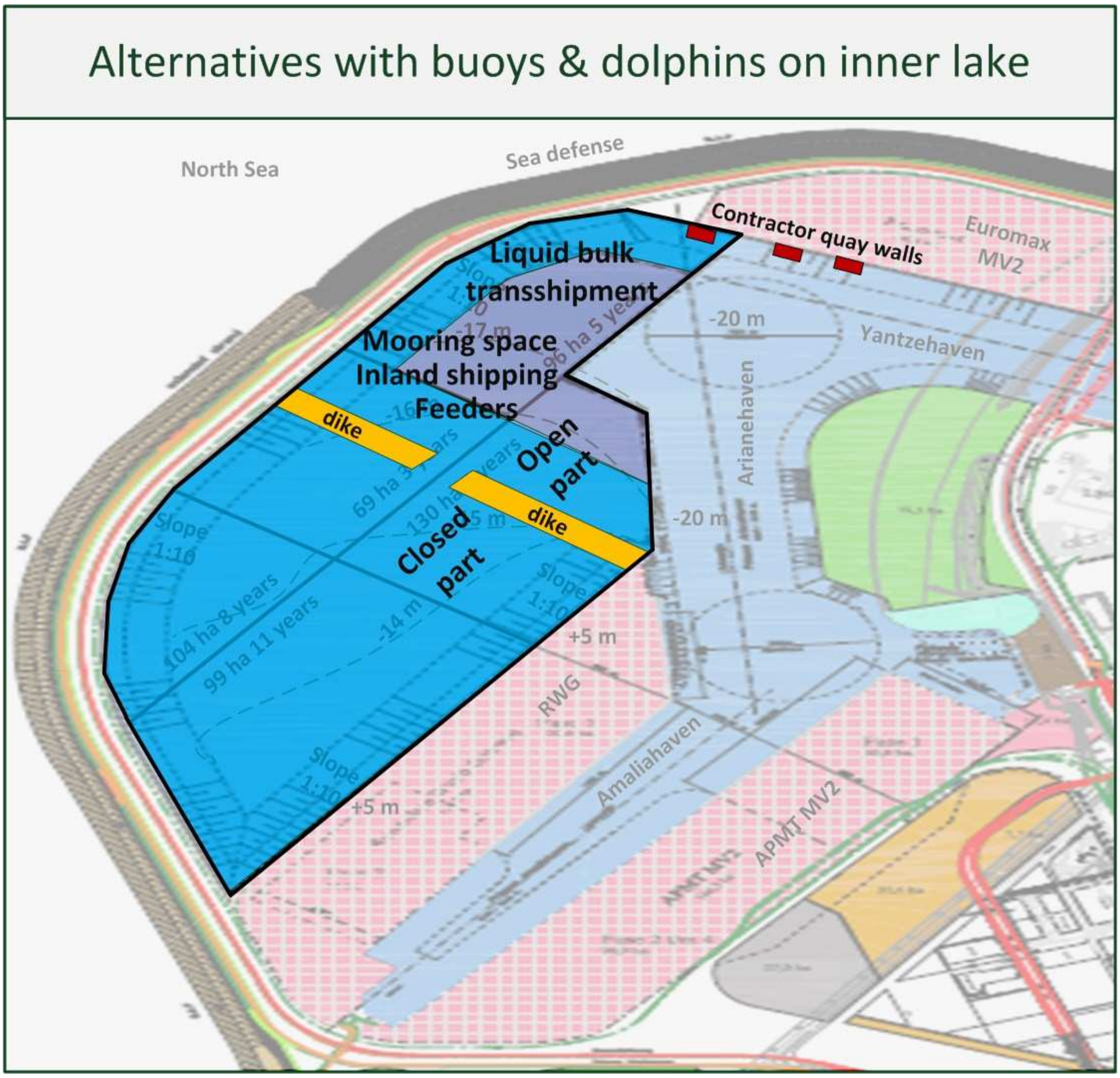


Figure 5-5: Allocation of vessel facilities on inner lake that require mooring facilities; close allocation to the Yantzehaven minimizes sailing times, and is required for large drafts

5.1.3 Jetties and quays

Hotel at work

Temporary workers on Maasvlakte 2 can be accommodated after 2015 in a floatel at the inner lake. A floatel requires a road connection and parking area. It should be allocated away from port activities due to noise and safety reasons *(see Figure 5-7).* A floatel requires mooring structure for the vessel and a jetty for its passengers. The contractor quay wall could be used to moor a floatel. Most floatels have a LOA of about 200 m, a width of about 30 m and a draft of about 7 m [30]. The contractor quay wall has an average water depth of 8 m. A jetty has to be constructed in case an average floatel is allocated at the inner lake *(see Figure 5-6).*

Fast ferry

The fast ferry transships passengers from one location to another. A line service with stops is only feasible from a minimum number of passengers. Stops for the fast ferry should be allocated adjacent to other activities and only be constructed if the amount of passengers is sufficient. The contractor quay can be used, in case enough passengers have to get off nearby *(see Figure 5-7).* If not, a jetty has to be constructed for a vessel with a LOA of 20 m, a width of 4 m and a draft of 2 m *(see Figure 5-6).*

Jetties

A jetty is a structure that is orientated perpendicular to the shore. It enables vessels to berth and passengers to board. Jetties have to transship passengers from vessel to shore and have to be allocated at the bank of the inner lake *(see Figure 5-7).* The dimensions of the structure depend on the site conditions and the vessels. The required water depth at the structure depends on the draft of the vessel, the keel clearance, the response of the vessel to waves, the tidal amplitude and bottom factors. Floatels have a draft of about 7 m and the fast ferry of about 2 m. The keel clearance amounts about 0.5 m, the response of the vessel to waves 0.25 m, the tidal amplitude 0.75 m and the bottom material factor 0.5 m [25]. This implies a required water depth at the structure of 9 m for floatel at work and 4 m for the fast ferry.

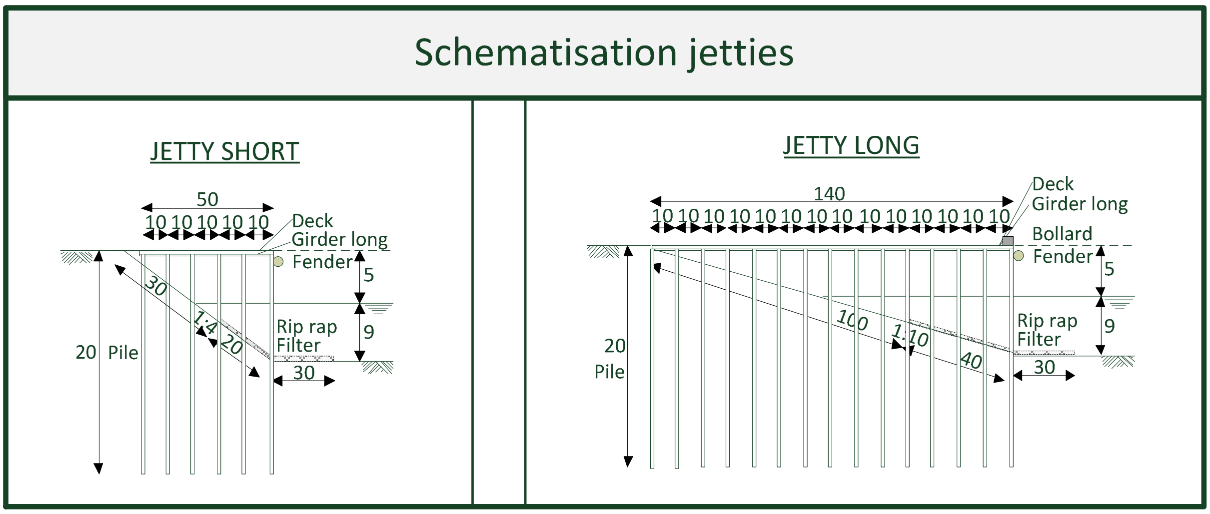


Figure 5-6: Side view jetties for hotel at work (not on scale); (left) short jetty constructed on an embankment of 1 over 4 with a facing, (right) long jetty constructed on the natural slope of 1 over 10 with a facing *(dimensions see Appendix B.1)*

The jetties on the inner lake can be constructed over the natural slope of 1/10 (long jetty), or at with a slope of 1/4 (short jetty) *(see Figure 5-6).* Regulations require the ground level of the structures to be at +5 m NAP in order to minimize flood risk [35]. The long jetty has a width of 140 m and short jetty has a width of 50 m for the floatel. A ground level at +5 m NAP makes less sense for the fast ferry. It has a deck far below +5 m NAP and will not sail at floods. A jetty with a ground level at +2 m NAP is constructed. The long jetty has a width of 60 m and the short jetty a width of 24 m *(see Appendix B.1).*

Dry bulk storage
Temporary storage of granite blocks requires several hectares for storage and a small quay for transshipment. The SMT Bontrup has a Death Weight Tonnage (DWT) of about 44,000, a Length Overall (LOA) of 201 m, a width of 28 m and a draft of 6 m [30]. The average water depth in front of the contractor quay walls is 8 m. This implies that the SMT Bontrup could discharge its cargo at high water. The site at the contractor quay walls amounts to several hectares and could be used for temporary storage of granite blocks *(see Figure 5-7).*

Wind turbine assembling
The inner lake can, as part of the Port of Rotterdam, play an important role for the installation of wind farms in the southern North Sea. However, different wind turbine sizes require different assembling sites.

Wind turbines, of about 5 MW, have gravity based foundations with a baseline of about 20 m and a height of 40 m. These foundations have a large working load, of about 100 kN/m^2, and are constructed with construction times of several years in a construction pit [6]. These sizes are rare and could be constructed in the closed part of the inner lake *(see Figure 5-7).*

Regular offshore wind turbines, of about 3 MW, have pile driven foundations and require more common port infrastructure, i.e. sites between 6 and 25 hectares, bearing capacities from 30 to 60 kN/m2, quay lengths of about 200 m, drafts larger than 6 m, warehouse facilities of about 1,000 m2 and 365 – 24/7 access for supporting vessels, oversize trucks [59]. Although the installation time for regular offshore wind turbines is, with several months, rather short, contractors sometimes need quays later again for maintenance. If contractors use lifting equipment that requires a quay length of about 50 m, the contractor quay wall can be used. If not, a dedicated quay has to be constructed *(see Figure 5-8).*

Common barge terminal
Inland vessels can transship their containers at one instead of at several terminals with a common barge terminal. It requires a quay to berth inland vessels and equipment to transship containers. Inland vessels have a LOA of 135 m, a width of about 10 m and a draft of about 5 m. In order to limit waiting times, the quay has to be able to berth several inland vessels simultaneously. Shorter waiting times also result into less required mooring spaces for inland vessels. The quay length depends on the number of vessels, their LOA and mooring length [25]. It is assumed that a vessel with a LOA of 135 m and a LOA of 110 m berth simultaneously. With mooring lengths of about 10 m a quay of 300 m is required. The common barge terminal has to be allocated in the open part of the inner lake, so that it is easily accessible for inland vessels and closely located to other the terminals *(see Figure 5-7).* The common barge terminal has to be accessible via road for employees, suppliers, emergency services and internal transport of containers to other terminals.

Dolphinarium

A dolphinarium requires facilities for sea mammals, animal fosters and visitors. Sea mammals stay in a basin or accommodation. The basin can comprise the inner lake, or a part of that. The closed part is more appropriate as there is less noise from vessels that sail past. The basin can amount several hectares and can be separated from the rest of the inner lake by a fence *(see Figure 5-7).* The accommodation has to be allocated at the basin and comprises of several square meters. Animals fosters require sheds to store food, detergents, medicines and buildings to manage the dolphinarium [12]. Visitors require a grandstand to see the animals and facilities to fulfill basic needs. The grandstand should be allocated as close as possible to the basin. The development plan Maasvlakte 2 prescribes a maximum surface area of 1,500 m^2 in order to minimize safety risks [35]. A single story building can be constructed with a width and length of about 40 m. The dolphinarium requires road connection and parking areas. It can be combined with the fast ferry, enabling visitors to combine a visit with a tour through the Port of Rotterdam and a day at the beach.

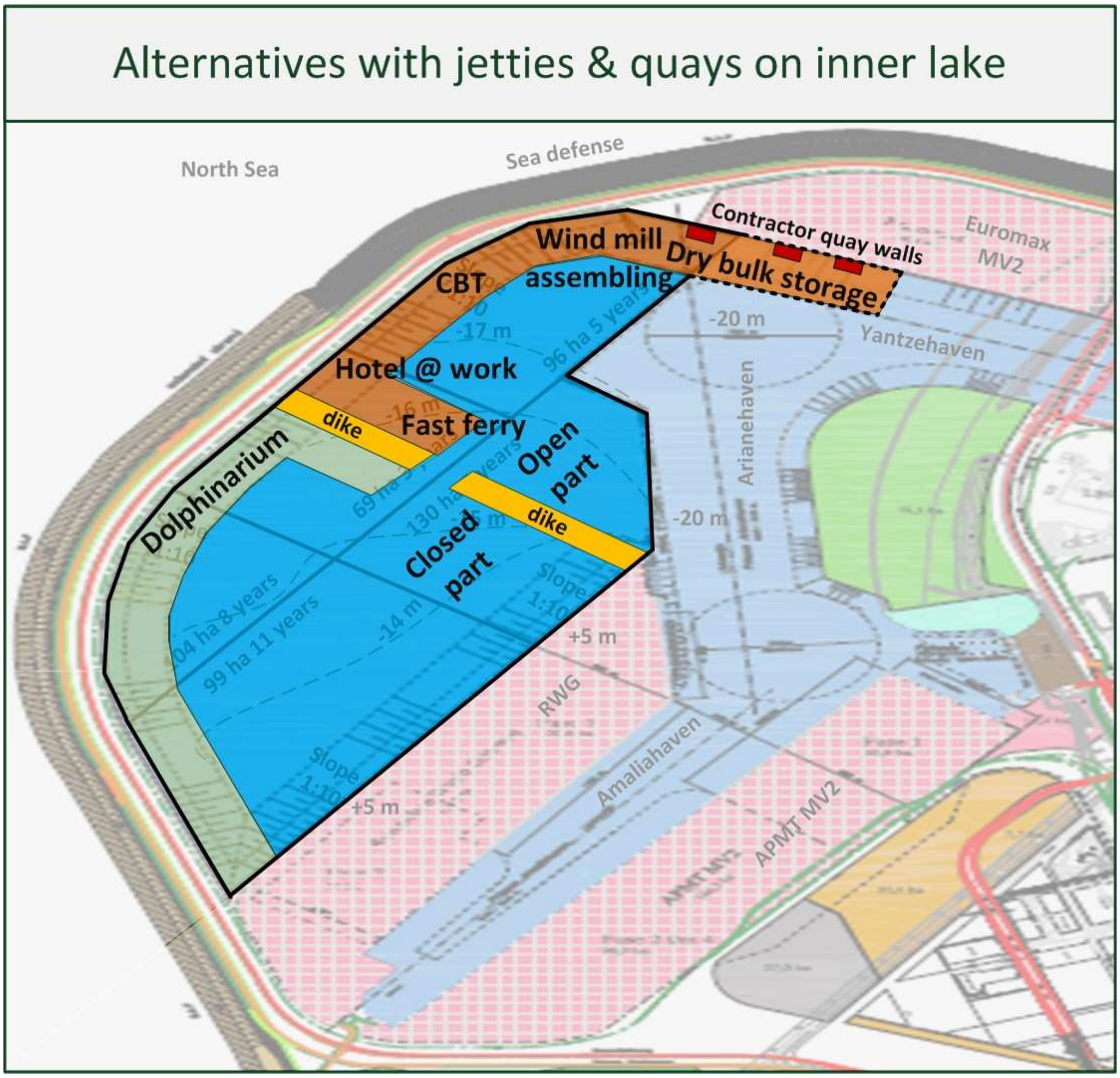


Figure 5-7: Allocation of passenger and freight facilities on inner lake; all activities require land-side and waterside access, most of them also require berthing facilities

Quays

A quay is a structure that is oriented parallel to the shore. It enables vessels to berth and to transship cargo. Quays have to be adapted to the requirements of the wind turbine assembling, common barge terminal and dolphinarium *(description quays see Chapter 4).* The activities require landside and waterside access. At the waterside the activities require a certain water depth. Lifting vessels have a draft of about 6 m. Inland vessels have a draft of about 5 m. The required water depth at the structures should be 2 m larger than the draft of the vessels *(see jetties Page 48).* The water depth at the wind turbine assembling quay should be 8 m and the water depth at the common barge terminal 7 m. Dolphins require several meters water depth. The activities require landside access and have to be allocated at the banks of the inner lake. Safety regulations stipulate that the ground level of the structures is at least at +5 m NAP.

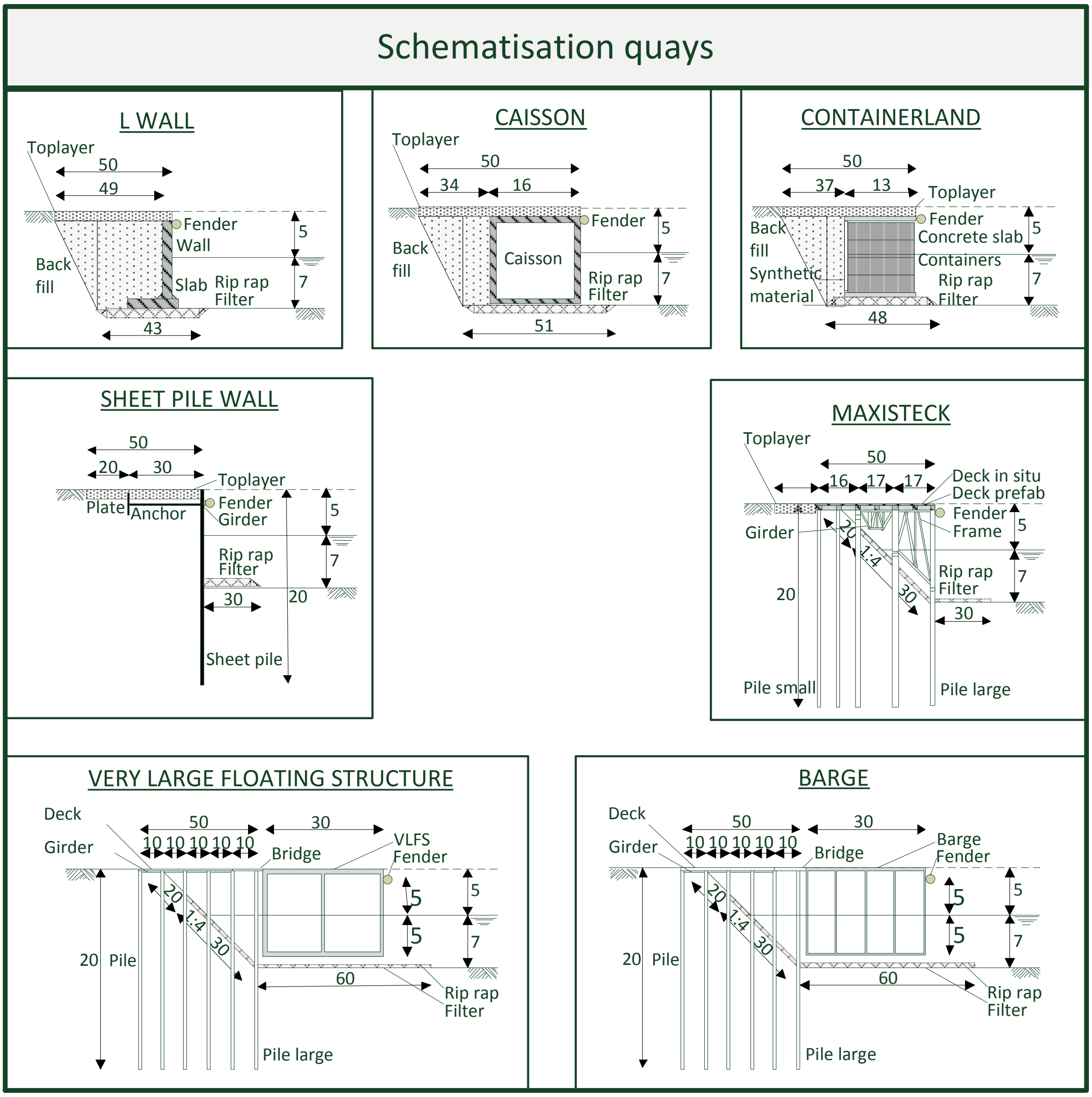


Figure 5-8: Side view quays common barge terminal (not on scale); L wall, caisson, container-land and sheet pile wall combine retaining with berthing function, a very large floating structure and barge require extra structures *(dimensions see Appendix B.1)*

Structures have to cope with the site conditions and fulfill these requirements in a different way. A sheet pile wall, caisson and L wall combine retaining and berthing functions. Containerland can probably withstand soil pressures, in case the containers are filled with sand, instead of with water [55]. However, further research is required. Maxisteck can be allocated at any slope. A facing is required to avoid erosion of the embankment. All bottom founded structures require a top layer to equalize unequal settlements *(see Figure 5-8).*

A very large floating structure and barge require an additional structure to connect the quay with the shore. A mooring structure has to absorb horizontal forces. A bridge facilitates the shore connection. The landward connection has to be flexible, as the ground level is fixed and the level of floating structures changes with the tide. A constant ground level can be maintained by discharging ballast water. All structures require a bottom protection to avoid erosion of the subsoil and mooring structures to berth and moor vessels *(see Figure 5-8).*

5.2 Conclusions

1) This chapter grouped activities with similar requirements. The requirements enabled to couple activities with structures and allocate them on the inner lake *(see Table 5-1, Table 5-2 and Table 5-3).*

2) The common barge terminal is the only activity that requires a quay. The objective of this research is to examine the possibility of allocating activities on the temporary inner lake, using port infrastructure *(see Section 1.3).* Next chapter elaborates the common barge terminal.

Alternatives with no structures (by PoRA)				
Activity		**Requirements**	**Structure**	**Allocation**
Water sports		- Parking area - Safety distance to vessels	- Parking area	- Closed part inner lake
Nature reserve		- Not next to other activities - No oil spillage		- Closed part inner lake
Wind energy		- Power cable - Center to center distance of about 500m - Boat or road access - Obstacle to water sports	- Wind mills (by operator)	- Closed & open part inner lake
Mussel farming		- Tidal range + flow - Fisher boat access - No oil spillage	- Sleeves (by operator)	- Closed & open part inner lake
Algae farming		- No oil spillage - Boat access	- Sleeves (by operator)	- Closed & open part inner lake

Table 5-1: Alternatives with no structures (by Port of Rotterdam Authority) for inner lake; (1st and 2nd column) activities, (3rd column) their requirements, (4th column) their structures and (5th column) allocation on the inner lake

Alternatives with buoys & dolphins				
Activity		**Requirements**	**Structure**	**Allocation**
Liquid bulk transshipment		- 150,000 DWT, 400x45x16 - Mooring facilities - Oil spillage measures - Safety distances - Tug assistence	- One dolphin or buoy per 50,000 DWT	- Until Suezmax, draft less than 16m in the open part inner lake next to Yantzehaven
Mooring spaces		- Inland vessels: 3,000 DWT, 135x10x5 - Feeders: 16,000 DWT, 170x30x10	- Dolphin or buoy for one or several vessels	- Open part inner lake next to Yantzehaven

Table 5-2: Alternatives with buoys & dolphins for inner lake; (1st and 2nd column) activities, (3rd column) their requirements, (4th column) their structures and (5th column) allocation on the inner lake

Alternatives with jetties & quays

Activity		Requirements	Structure	Allocation
Hotel at work		- Floatel: 200x30x7 m - Road connection - Parking area - Not next to activities that cause noise	- Jetty with retaining height of 14m, width 1/10: 140m width 1/40: 50m	- Open part inner lake next to sea defense or temporary dike
Fast ferry		- Ferry: 20x4x2 m - Minimum amount of passengers	- Jetty with retaining height of 6m, width 1/10: 60m width 1/4: 24m	- Open part inner lake next to sea defense or temporary dike
Dry bulk transshipment		- 44,000 DWT, 201x28x6 - Several hectares for storage	- Contractor quay wall	- Open part inner lake at contractor quay wall
Wind mill assembling		- 6-25 ha, 30-60kN/m2 - Quay=200m, draft=6m - 365/24 access for oversize trucks & vessels - warehouse of 1,000m2	- Contractor quay wall - Or, dedicated quay with length of 200m & retaining height 13m	- Open part inner lake next to sea defense or temporary dike
Common barge terminal		- 3,000 DWT, 135x10x5 - Terminal equipment - Quay=300m, draft=5m - Road & vessel access	- Dedicated quay with length of 300 m and retaining height 12m	- Open part inner lake next to sea defense or temporary dike
Dolphinarium		- Basin & accommodation - Sheds, grandstand, facilities basic needs - road access, parking area	- Quaytype structure LxWxRH: 50x50x8m - Fence to separate basin from inner lake	- Closed part inner lake next to beach or temporary dike

Table 5-3: Alternatives with jetties & quays; (1st and 2nd column) activities, (3rd column) their requirements, (4th column) their structures and (5th column) allocation on the inner lake

6 Common barge terminal

This chapter elaborates the common barge terminal. Section 6.1 illustrates the costs of a deep sea quay expansion and a common barge terminal. Section 6.2 defines a formula for the increase in quay efficiency and calculates the additional capacity created by the common barge terminal at the deep sea quays at Maasvlakte 2. Section 6.3 calculates the net cost savings of postponing the realization of a deep sea quay.

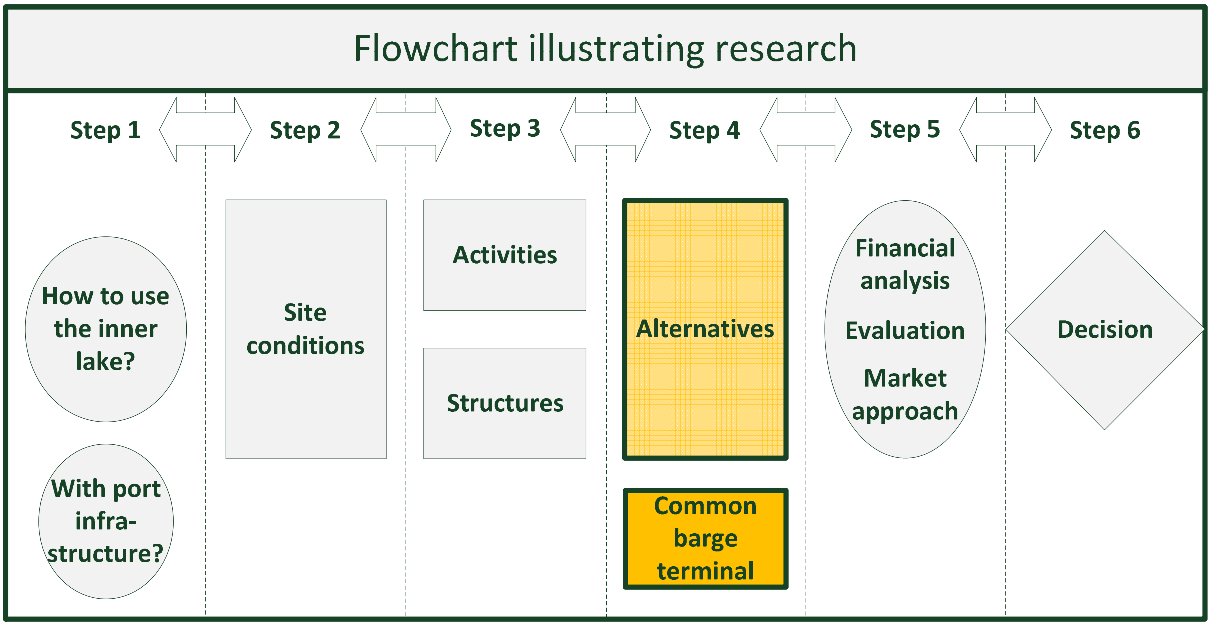


Figure 6-1: Flowchart illustrating research, chapter 6; Description of common barge terminal's principle, determination of quay efficiency and net cost savings due to postponing realization deep sea quay

6.1 Principle

Consequences for Maasvlakte 2
A common barge terminal is a neutral transshipment point for inland vessels. Its usage has consequences for Port of Rotterdam Authority, terminal operators and inland vessels *(see also Section 3.2.1).* This research examines the financial viability of various activities on the temporary inner lake for Port of Rotterdam Authority. Only consequences that have a direct impact are discussed:

i) It eliminates the hopping of inland vessels: Inland vessels usually transship their containers in small call sizes at several terminals in a port. A common barge terminal enables inland vessels to transship their containers at one dedicated quay *(see also Figure 3-7)*. Eliminating hopping is valuable for inland vessels that are behind schedule and have to gain time to meet delivery times [55] *(not examined in this research).*
ii) It reduces the need for an empty depot: Inland vessels transport empty containers to the Port of Rotterdam on a regular basis. Empties leave the port with sea going vessels irregularly in large chunks [55]. Usually empty containers stay longer in the stack than full containers. Transshipping and storing empties at a common barge terminal increases the quay and stack capacity *(not examined in this research).*

iii) It enables postponing deep sea quay expansions: Inland vessels are served by fewer cranes than sea going vessel *(see Figure 6-5).* They tranship fewer containers per quay length and time [70]. Handling inland vessels at a common barge terminal creates additional capacity at a deep sea quay. Additional capacity enables to postpone deep sea quay expansions and therefore to save costs for Port of Rotterdam Authority *(see Section 6.3)* and the terminal operators *(not examined in this research).*

iv) It requires a transportation system: Inland vessels do not tranship their containers anymore at the deep sea quay, but at elsewhere in the port. The containers have to be transported from the common barge terminal to the deep sea terminal and vice versa *(see Figure 6-2).*

v) It requires port infrastructure and terminal equipment: Inland vessels have to tranship their containers at the common barge terminal. Quays and mooring facilities enable vessels to berth and support terminal equipment *(costs see Chapter 7).* Cranes lift the containers from the inland vessel *(costs see Appendix C.2).*

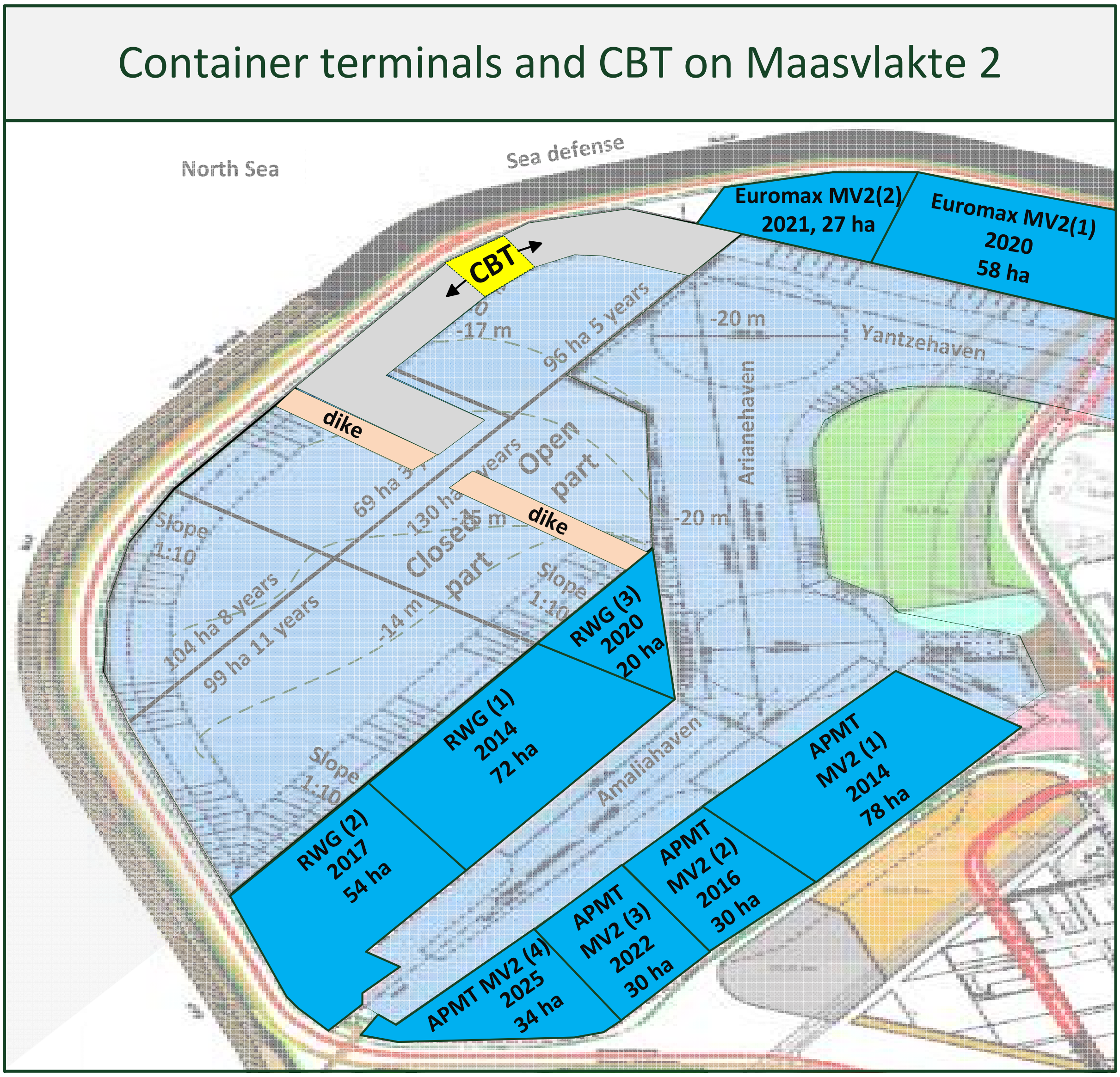


Figure 6-2: Container terminals (blue) on Maasvlakte 2: expansion phases (in brackets), inauguration date (years), surface (hectares) and common barge terminal (CBT): possible location (grey), surface (yellow)

Need for expansion
Container terminals on Maasvlakte 2 are developed in phases, in response to client demand *(see Figure 6-2).* In the first years of operation the throughput of containers is lower than the terminal's capacity *(see Figure 6-3, left)*. Over the years the throughput is expected to increase. The forecasted throughput of containers grows in the Port of Rotterdam on average with 6% per year [53]. As the throughput increases the terminal operator's revenues and costs increase. The optimal throughput for the terminal operators is 23,000 TEU/ha/y [70].

As the throughput increases further the loss of income due to congestions approaches the costs of additional capacity. Congestion costs are caused by overtime penalties and reshuffling containers. Terminal operators have service time agreements with shipping companies. Exceeding service times lead to penalties and finally to a loss of customers [55]. Terminal operators have at larger throughputs more containers in larger stacking heights. Larger stacking heights increase the re-shuffling probability and costs [62]. The maximum throughput for the terminal operators is 27,700 TEU/ha/y [70].

Deep sea quay expansion
Additional capacity can be created through a deep sea quay expansion *(see Figure 6-3, left)*. The development of a new port area gives a terminal operator more space to handle containers, i.e. the throughput per surface decreases *(see year 3).*

Port of Rotterdam Authority invests in a deep sea quay to generate more revenues *(see Figure 6-3, right).* Investment costs occur before the maximum throughput is reached *(see year 2)* and result in additional future revenues *(see year 3).*

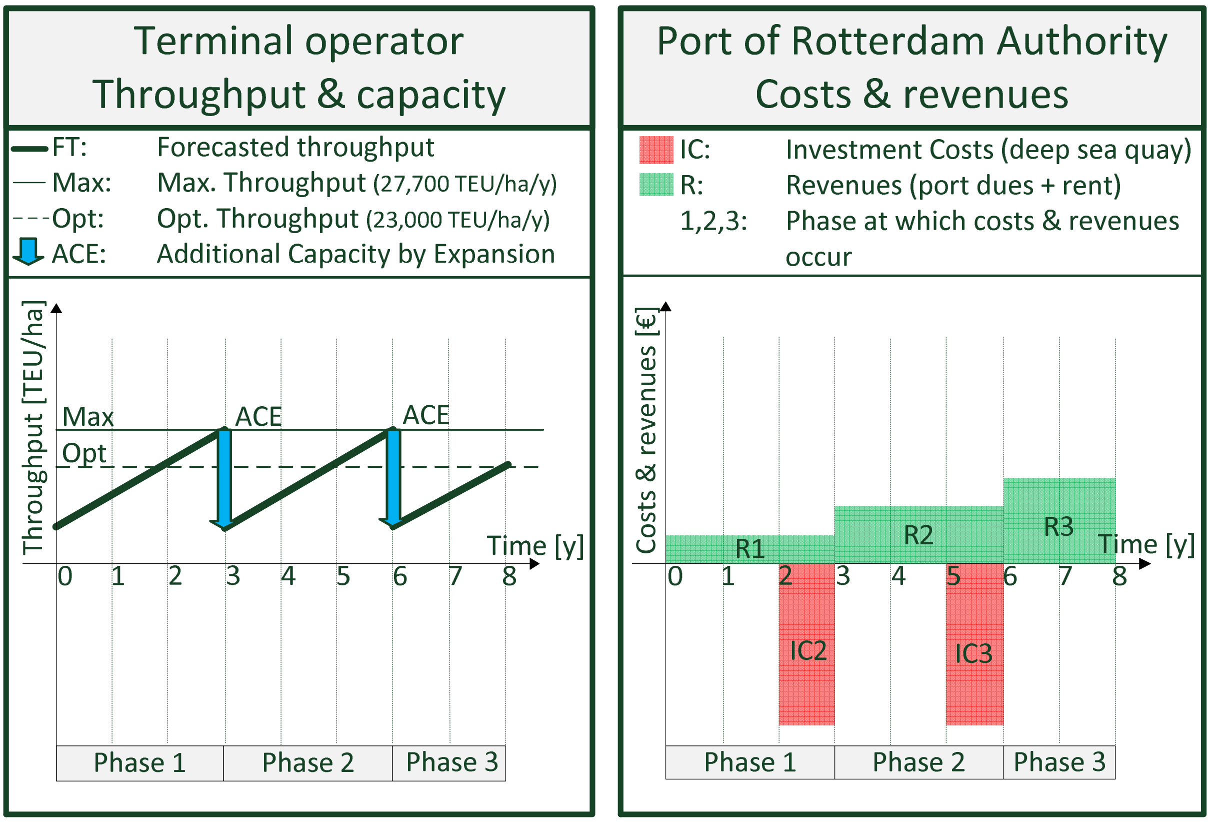


Figure 6-3: Phased deep sea expansions in a regular port; (left) increase in throughput at the terminal and (right) investments in deep sea quays and additional revenues

Common barge terminal

Additional capacity can also be created by realizing a common barge terminal *(see Figure 6-4, left).* A common barge terminal handles inland vessels at a dedicated quay instead of at a deep sea quay. Terminal operators have more time and space to handle sea going vessels. Sea going vessels are served by more cranes and can therefore tranship more containers per time and quay length, i.e. additional capacity is created *(see year 3).* After a while the forecasted throughput surpassed the additional capacity and the deep sea quay has to be expanded *(see year 4).* The common barge terminal enables to postpone a deep sea quay expansion.

Port of Rotterdam Authority can postpone its deep sea quay investments *(see Figure 6-4, right).* Postponing investment saves costs, as the future value is lower than the present value, and lead to a loss in rent, as terminal operators the port areas later *(see year 3).*

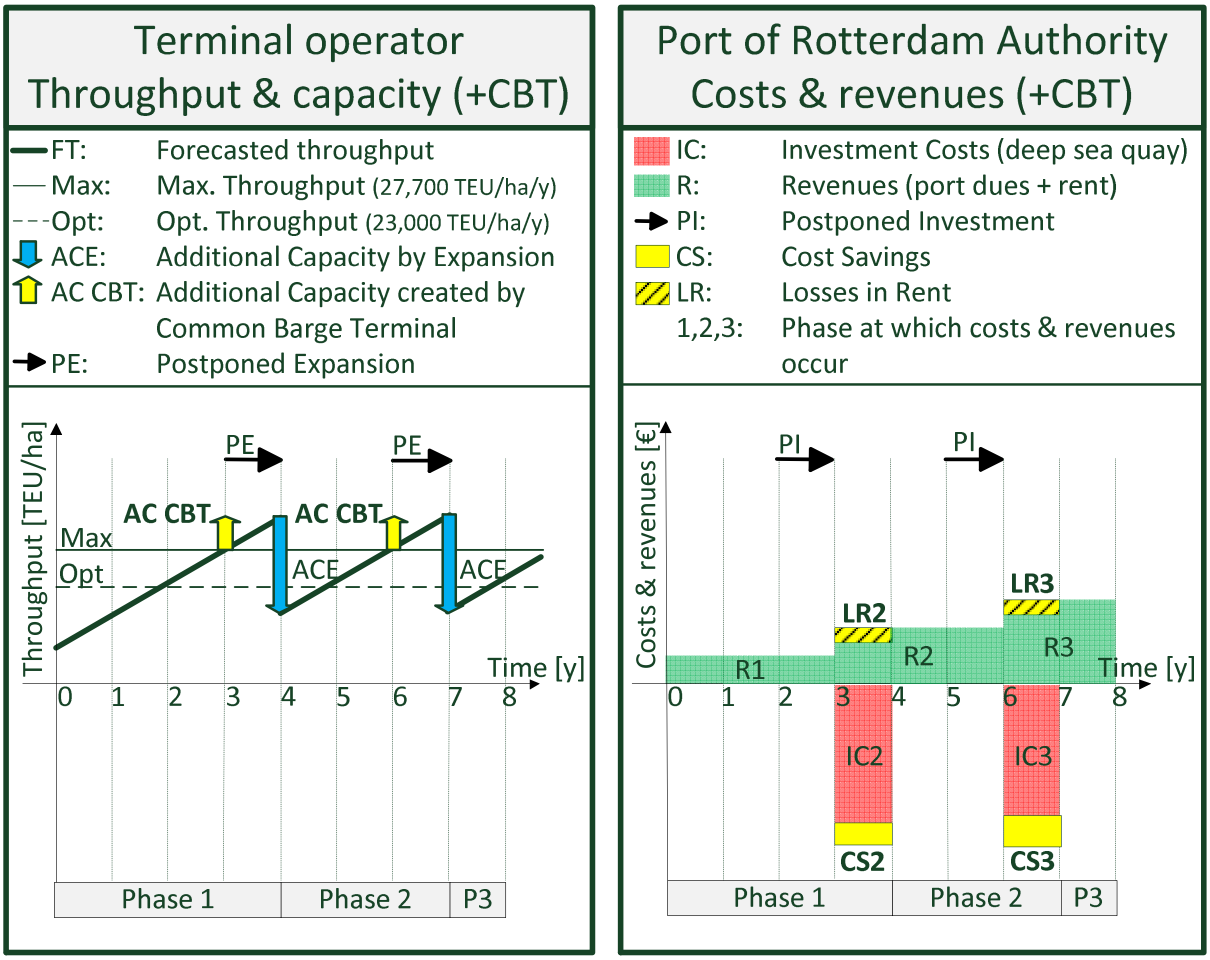


Figure 6-4: Phased deep sea expansions in a port with common barge terminal; (left) additional capacity created by common barge terminal and (right) cost savings, losses in rent

A common barge terminal is financially viable for Port of Rotterdam Authority, in case:

- The additional capacity created by the common barge terminal is larger than the additional forecasted throughput *(see Section 6.2).*
- The cost savings and losses in rent (see Section *6.3*) are larger than the investment costs of the inland quay for the common barge terminal and its rent *(see Section 7.3.2).*

6.2 Additional throughput and capacity

Additional throughput
The additional forecasted throughput at the deep sea quay is determined by multiplying the maximum throughput (27,700 TEU/ha/y) with the terminal's surface *(see Figure 6-2)* and the average annual throughput growth *(about 6% see Appendix C.1).*

Additional capacity
The additional capacity created by the common barge terminal at the deep sea quay is determined by multiplying the throughput of the small call sizes with the relative quay efficiency:

- The throughput of the small call sizes indicates how much containers can be handled at the common barge terminal instead of at the deep sea quay. The modal split indicates that 39% of the throughput is transshipped via inland vessels [54]. Simulations show that 3% of the inland vessels transship at most 25 TEU and 6% at most 50 TEU at Maasvlakte [55]. This implies that 1.05% and 2.10% of the throughput is transshipped in call sizes of maximum 25 TEU and 50 TEU respectively.
- The relative quay efficiency indicates how much containers can be handled additionally at the deep sea quay by handling 1 TEU at the common barge terminal. It is calculated by dividing the quay efficiency of a sea going vessel by the quay efficiency of an inland vessel (see *Table 6-1*).

Relative quay efficiency
Inland vessels transship fewer containers per quay length per time than sea going vessels at a deep sea quay. They have a lower deep sea quay efficiency. The vessel's quay efficiency is determined by vessel's required quay length and turnaround time. The required quay length is determined by the vessel's LOA and mooring length. The turnaround time is determined by the number of cranes, the crane capacity, the vessel's call size and berthing time *(see Figure 6-5 and Figure 6-6).*

Figure 6-5: (left) Seagoing vessels are served by more cranes than (right) inland vessel than can transship more containers per quay length and time

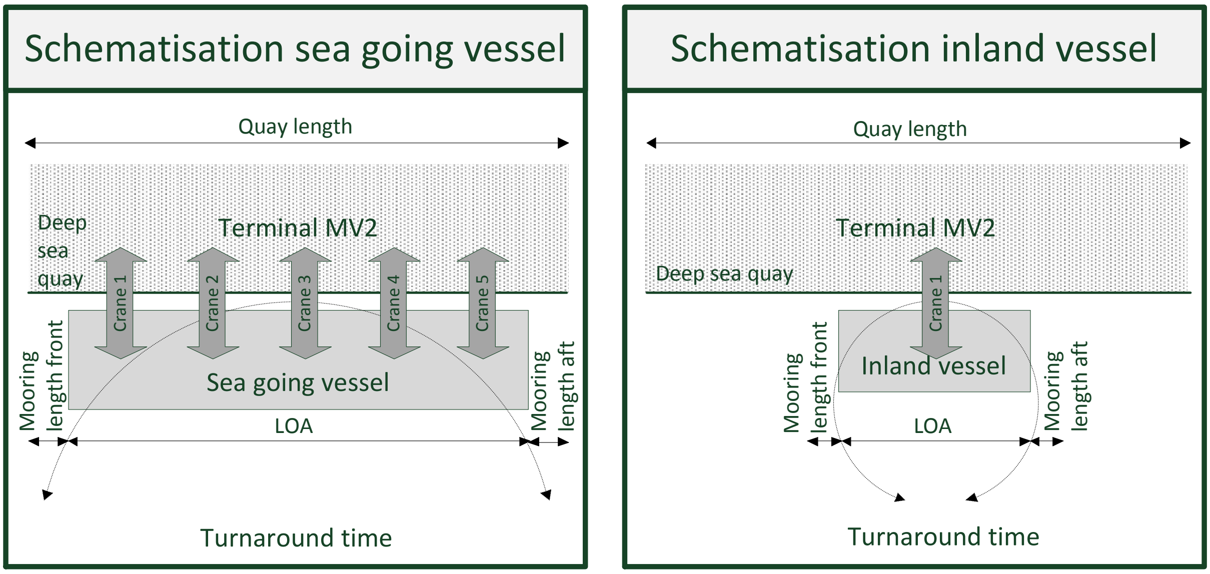


Figure 6-6: Parameters that determine the deep sea quay efficiency (left) for a sea going vessel and (right) an inland vessel

This research determines the quay efficiency of an inland vessel with a call size of 25 TEU, a call size of 50 TEU and a sea going vessel with a call size of 3,400 TEU [70]. The inland vessels have a LOA of 110 m and a mooring length of 10 m. A sea going vessel has a LOA of 310 m and a mooring length of 30 m. Inland vessels can (de)berth in about three-quarter of an hour, seagoing vessels in about one hour and a half [70]. Terminals use on average one crane on inland vessels and five cranes on seagoing vessels. A crane usually moves about 25 containers per hour, or with a TEU factor of 1.65, about 41.25 TEU per hour [54] [55]. The quay efficiency is calculated by dividing the vessel's call size by its LOA, mooring length, berthing time and transshipment time. The relative quay efficiency is calculated by dividing the quay efficiency of the sea going vessel with the quay efficiency of the inland vessels *(see Table 6-1).*

Relative quay efficiency							
Vessel	Call size [TEU]	LOA [m]	Mooring length [m]	Berthing time [h]	Transshipment time [h]	Quay efficiency [TEU/m/h]	Relative quay efficiency [-]
Inland 25	25	110	10	0,75	0,61	0,1536	3,6192
Inland 50	50	110	10	0,75	1,21	0,2124	2,6184
Sea going	3400	310	30	1,50	16,48	0,5560	1,0000

Table 6-1: Vessel's characteristics at a deep sea quay; inland vessels with small call sizes have a lower transshipment rate than sea going vessels

Additional throughput and capacity

The additional forecasted throughput and capacity created by the common barge terminal is calculated for each deep sea quay expansion at Maasvlakte 2. The additional forecasted throughput at the deep sea quay is larger than the additional capacity created by handling <25 TEU call sizes and smaller than call sizes smaller than <50 TEU call sizes at the common barge terminal *(see Figure 6-7).*

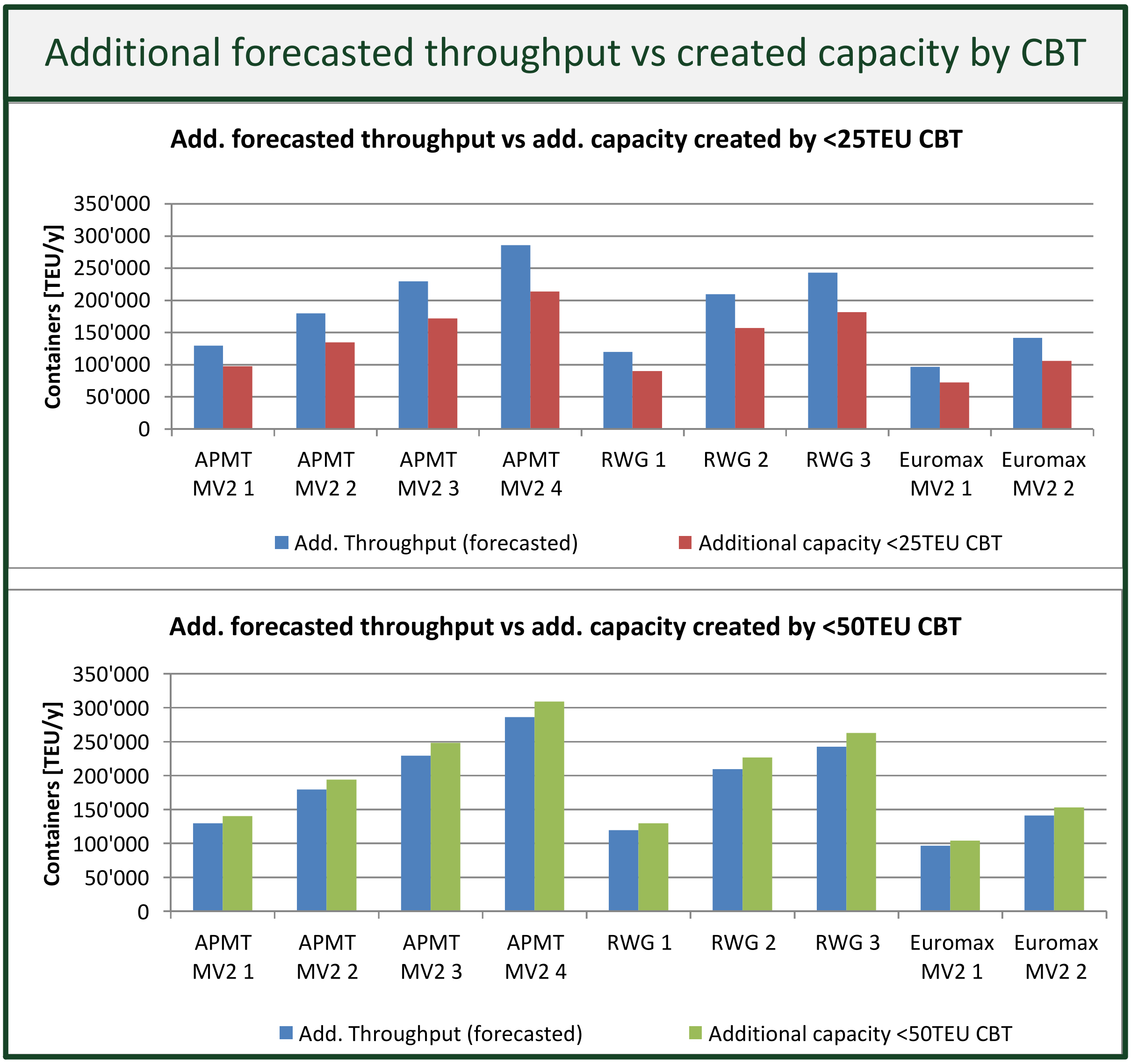


Figure 6-7: Additional throughput at deep sea quay (blue, left column) versus additional capacity by 25 TEU call sizes (top, red, right column), 50 TEU call sizes (bottom, green, right column)

6.3 Net present cost savings

Principle

Port of Rotterdam Authority has to respond to an increase in container throughput with the realization of additional capacity. Doing nothing results in congested terminals and at the end to a loss of customers. Port of Rotterdam Authority should either expand the deep sea quay or realize a common barge terminal. A comparison of the differences is sufficient to identify the most profitable option *(see Figure 6-3 and Figure 6-4).*

The creation of additional capacity by a common barge terminal results in cost savings and a loss in rent compared to a deep sea quay expansion. Port of Rotterdam Authority can save costs and lose rent at moments in time. The net present cost savings cumulate all cost savings and losses in rent and take the decrease in value over time into account with a discount rate *(see Section 7.3).*

Cost savings
The investment costs of a deep sea quay wall are estimated at present per quay length at 55,000 €/m. The value of the investment costs is one year later, with a discount rate of 10%, 50,000 €/m (55,000/1.1) [42]. Postponing investments in a deep sea quay one year saves 5,000 €/m. Some terminals at Maasvlakte 2 also have a dedicated quay for feeders. Postponing feeder quay investments one year saves 3,500 €/m (35,000 – 35,000/1.1) [42].

Losses in rent
Port of Rotterdam Authority generates on average about 5.21 €/m^2 per year with its sites *(see Section 7.2.2)*. This research assumes that terminal operators have to buy an option, when their deep sea quay expansions are postponed. An option costs 25% of the rent [55]. The sites on Maasvlakte 2 have a width (perpendicular to the quay length) of about 600 m. Postponing a deep sea expansion for one year leads to a loss in rent of 2344.50 €/m (5.21*(1-0.25)*600).

Net present cost savings
The cost savings and losses in rent of all deep sea quay expansions together give the net present cost savings of the common barge terminal at Maasvlakte 2. The net present cost savings are about 4 M€. The realization of the first phase of APMT Maasvlakte 2 and RWG 1 already started. Postponing the realization of these deep sea quays is not possible anymore *(see Figure 6-8)*.

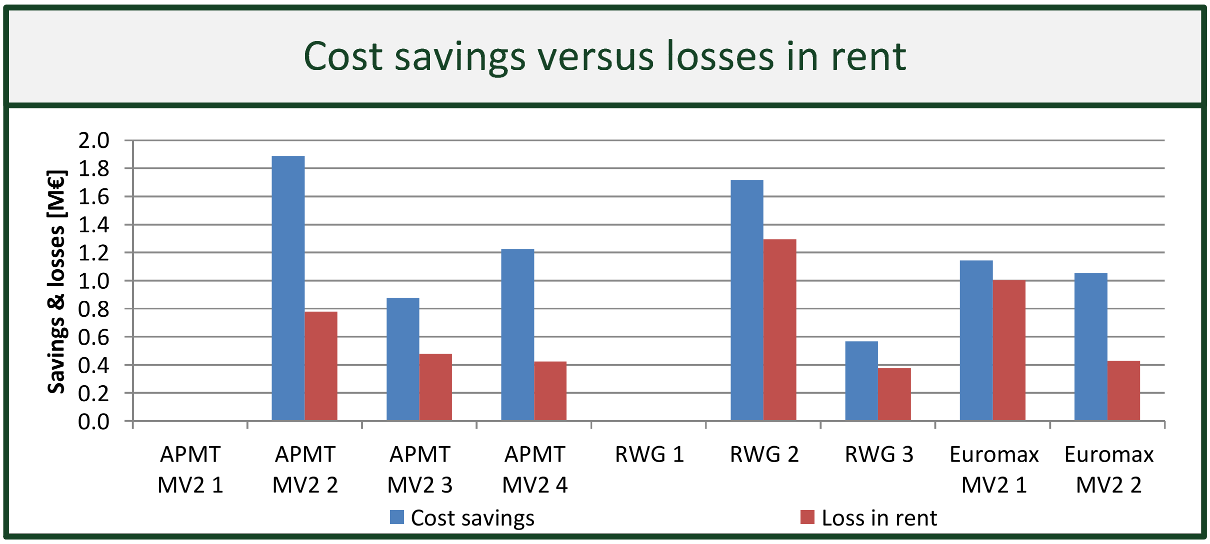


Figure 6-8: Net present cost savings postponing deep sea quay expansions, discount rate of 8.5%; cost savings (blue, left column) and losses in rent (red, right column)

Sensitivity analysis
The parameters used in this research are based on expert opinions. Parameters that are driven by economic motives are highly subject to change. Therefore the net present cost savings are determined for several discount rates, throughputs of the small call sizes and container throughput grow percentages *(see Figure 6-9 and Appendix C.2).*

- The discount rate determines the required profitability on a project. Governments use about 4.5% and private organizations 12.5%. Port of Rotterdam Authority uses a discount rate somewhere in between, 8.5% is taken *(see Section 7.3.1).*

- Simulations indicate that 1.05% of the throughput at Maasvlakte is transshipped in at most 25 TEU and 2.10% in at most 50 TEU call sizes. These percentages result market information on the amount of containers per vessel type and are varied by 1.5 and 2 (small call size factor).
- The average forecasted increase in throughput is based on four economic scenarios. The increase can be smaller or larger. The low growth scenario indicates an increase of about 3% and the global economy scenario of about 9% *(see Appendix C.1).*

The net present cost savings are about 4 M€ for a small call size of <50TEU, discount rate of 8.5%, small call size factor of 1 and annual increase in container throughput of 6%. Port of Rotterdam Authority is only interested in larger net present cost savings. The investment costs of an inland quay for the common barge terminal are several times larger than the rent the common barge terminal pays *(see Section 7.2)*.

The net present cost savings are larger in case:

- Call sizes are larger: The additional capacity created by the common barge terminal is determined by the relative quay efficiency and throughput of the small call sizes. The additional capacity by handling <25TEU is 3.80% (3.62*1.05%) and <50TEU is 5.50% (2.62*2.10%) of the throughput at the deep sea quay.
- Discount rates are larger: The present values of future investments are calculated with a discount rate. Larger discount rates increase the differences between future and present values. The net present cost savings are 7 M€ for a discount rate of 12.5%.
- Small call size factors are larger: The throughput of the small call sizes (<25TEU is 1.05% and <50TEU is 2.10%) is multiplied with a small call size factor. The net present cost savings are 15 M€ for a small call size factor of 2.
- Increase in throughput is smaller: The additional forecasted throughput is determined with the current throughput and annual growth in container throughput. A smaller growth results in a smaller additional forecasted throughput. The net present cost savings are 15 M€ for an annual growth of 3%.

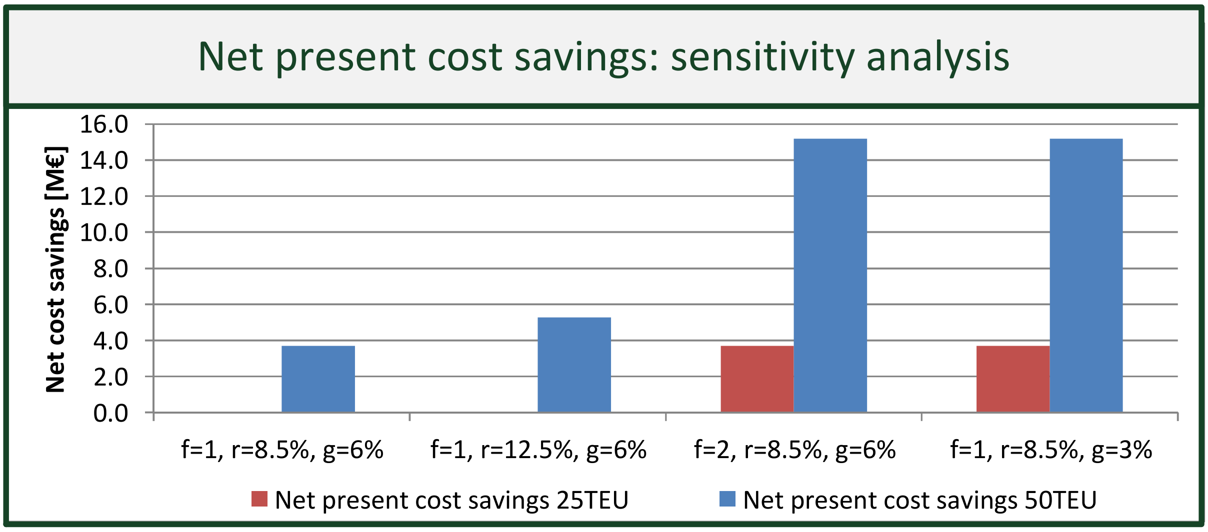


Figure 6-9: Net present cost savings for medium input parameters (left), a large discount rate (r, middle left), large small call size factor (f, middle right), low throughput grow percentage (g, right) for <25 TEU (blue, left column) and <50 TEU (red, right column)

6.4 Conclusions

This chapter described the principle of a common barge terminal and calculated the net present cost savings for Port of Rotterdam Authority:

1) The realization of a common barge terminal has several effects on Maasvlakte 2:
   a) It eliminates the hopping of inland vessels from one terminal to another,
   b) It decreases the need for a depot of empty containers,
   c) It enables to postpone investments in deep sea quay expansions (→ this chapter),
   d) It requires a transportation system to bring containers to deep sea quays and back,
   e) It requires port infrastructure and equipment to tranship and store containers.

2) The common barge terminal increases the deep sea quay capacity at high occupancy rates by handling inland vessels at a dedicated quay. A deep sea quay expansion can be postponed as long as the additional throughput is smaller than the additional capacity. Postponing deep sea quay expansions saves costs:
   a) The additional throughput is calculated by multiplying the optimal terminal throughput with the terminal's surface and annual forecasted throughput increase.
   b) The additional capacity is calculated by multiplying the throughput of the inland vessels with the relative quay efficiency:
      - The throughput of inland vessels that tranship at most 25 and 50 TEU indicates how much containers are transhipped at the common barge terminal. It is determined with the modal split and simulation results as ratio of the throughput.
      - The relative quay efficiency indicates how much containers can be handled additionally at the deep sea quay by handling 1 TEU at the common barge terminal. It is determined with the call size, required quay length and turnaround time of an inland and sea going vessel.
   c) The net present cost savings are calculated by adding all cost savings and loss of rent of each postponed quay expansion at Maasvlakte 2 together:
      - The cost savings are determined with investment costs' key figures and a discount rate over time.
      - The losses in rent are determined with average rent per surface, the average width of the sites and a percentage of an option.

3) The net present cost savings are calculated several values of input parameters:
   a) Port of Rotterdam Authority is only interested in net present cost savings of at least 10 M€. The investment costs of an inland quay for the common barge terminal are several times larger than rent paid by the common barge terminal operator.
   b) The net present cost savings are about 15 M€ in case:
      - <50TEU call sizes are handled at the common barge terminal,
      - Future investments are discounted with at least 8.5% and,
      - At least 4.20% is transhipped in inland vessels with call sizes of < 50 TEU and the annual growth in container throughput is at most 6% <u>OR</u> at least 2.10% is transhipped in small call sizes and the annual growth is at most 3%.

7 Financial analysis

This chapter determines the financial viability of the alternatives. Section 7.1 illustrates how value is created with port infrastructure and what costs and revenues occur over a port infrastructure's lifecycle. Section 7.2 determines the costs and revenues by their lifecycle phase and illustrates reuse-possibilities for the structures. Section 7.3 analyzes with the net present costs and revenues the financial viability of each alternative.

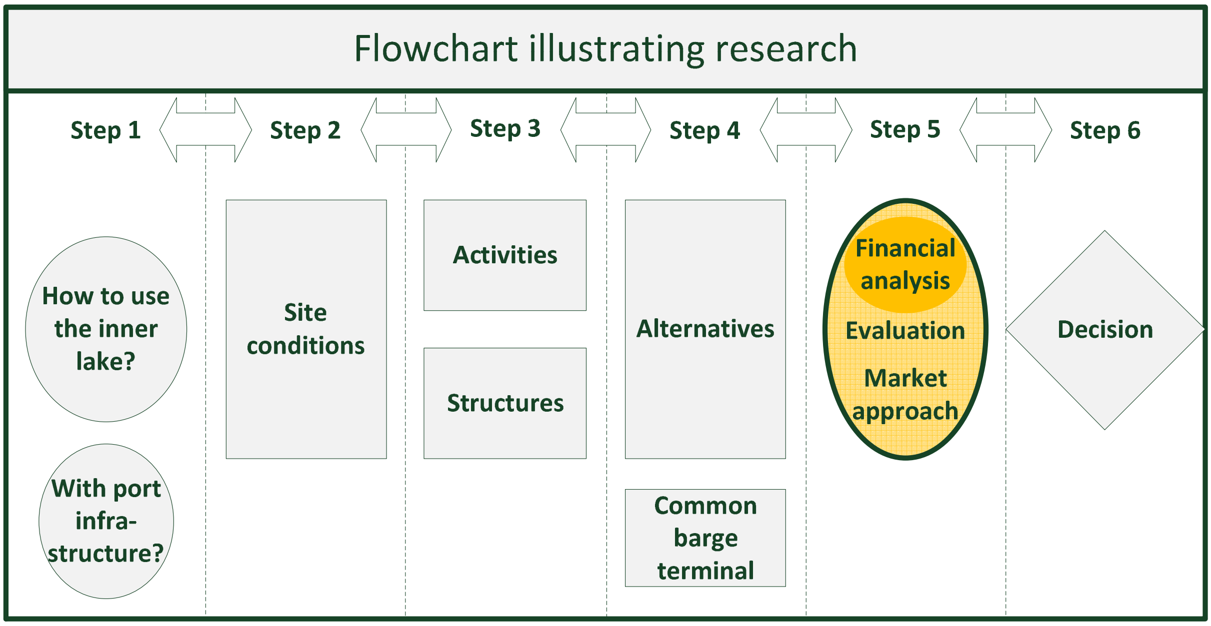


Figure 7-1: Flowchart illustrating research, chapter 7; determination of the costs, revenues, functional and technical value of the alternatives over whole lifecycle

7.1 Principle

Costs and revenues

Port of Rotterdam Authority creates value for its customers and generates income with port infrastructure. The realization of port infrastructure requires investments. Port of Rotterdam Authority spends investment, operational and demobilization costs and receives port dues and rent in return. Costs and revenues differ per structure. As the retaining height of the structure increases, not only the investment costs increase, but also the vessel sizes. Larger vessels usually tranship more cargo and generate more port dues for Port of Rotterdam Authority [65]. Costs and revenues vary over time. Costs occur over the lifetime of the structure. Revenues only occur over the service life of the structure. Hence, the financial viability of an alternative depends on its costs and revenues, over its service life and lifetime *(see Figure 7-2).*

Sometimes even financial non-viable structures are constructed. Port infrastructure is never a stand-alone product, but requires other port infrastructure. A quay for example will never handle any ships without a port channel. Therefore Port of Rotterdam Authority does not measure its profitability over a single project, but over all its projects. If a necessity exists and no revenues can be retrieved, the structure with the lowest lifecycle costs is constructed.

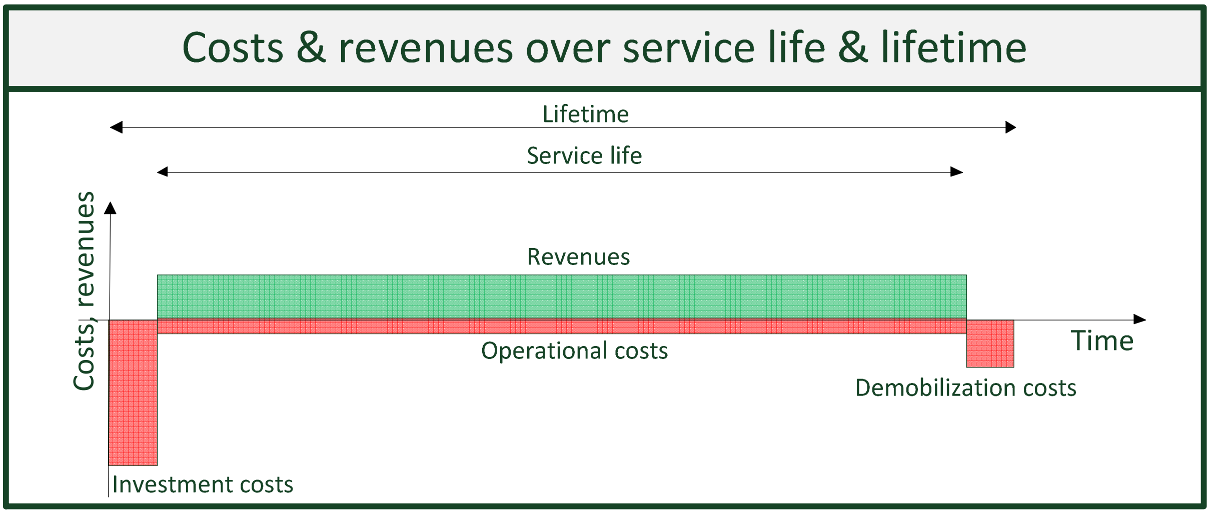


Figure 7-2: The financial viability of an alternative depends on costs and revenues over a structure's service life and lifetime

Functional and technical value

Shipping companies call and terminal operators rent sites at the Port of Rotterdam, if they can make use of decent port infrastructure at reasonable prices. The port customer's desired value is usually specified with functional requirements, such as the structure's retaining height and bearing capacity [65]. The structure's functional value has to be larger than customer's functional requirements *(see Figure 7-3, top).*

Not all needs of a customer are specified into functional requirements. Customer's needs change over time. Vessel sizes usually grow over the years [19]. Larger vessels require larger structures with larger retaining heights, heavier loading equipment and therefore also structures with larger bearing capacities [33]. The need of a customer can abate over time. Port of Rotterdam Authority has to find another customer for its port infrastructure. Usually a structure can only fulfill some new user requirements. A new customer might for example use similar vessels sizes, but another type of cargo that requires larger cranes and a larger bearing capacity. Hence, port infrastructure has to cope with an increase in functional requirements *(see Figure 7-3, top).*

The safety of the structures against various environmental and user loads is ensured by technical requirements [65]. The decrease in the structures' strength by natural processes, such as corrosion, can be delayed by maintenance, but not prevented [33]. This implies that the technical value decreases over time *(see Figure 7-3, middle).*

After the functional requirements surpassed the functional value, or the technical value declined under the technical requirements the service life of the structure ends. The service life of port infrastructure has drastically decreased in the Port of Rotterdam over the past 150 years. Functional requirements change faster. Whereas quays in the city port still served for about 150 years, nowadays the service life of new structures varies between 15 and 25 years [19][33]. Most structures still have a technical lifetime of about 40 years and could serve port activities longer than 15 to 25 years. The decrease in service life usually results in far less revenues over little less costs and a considerable rest value, i.e. capital is destructed *(see Figure 7-3, middle and bottom).*

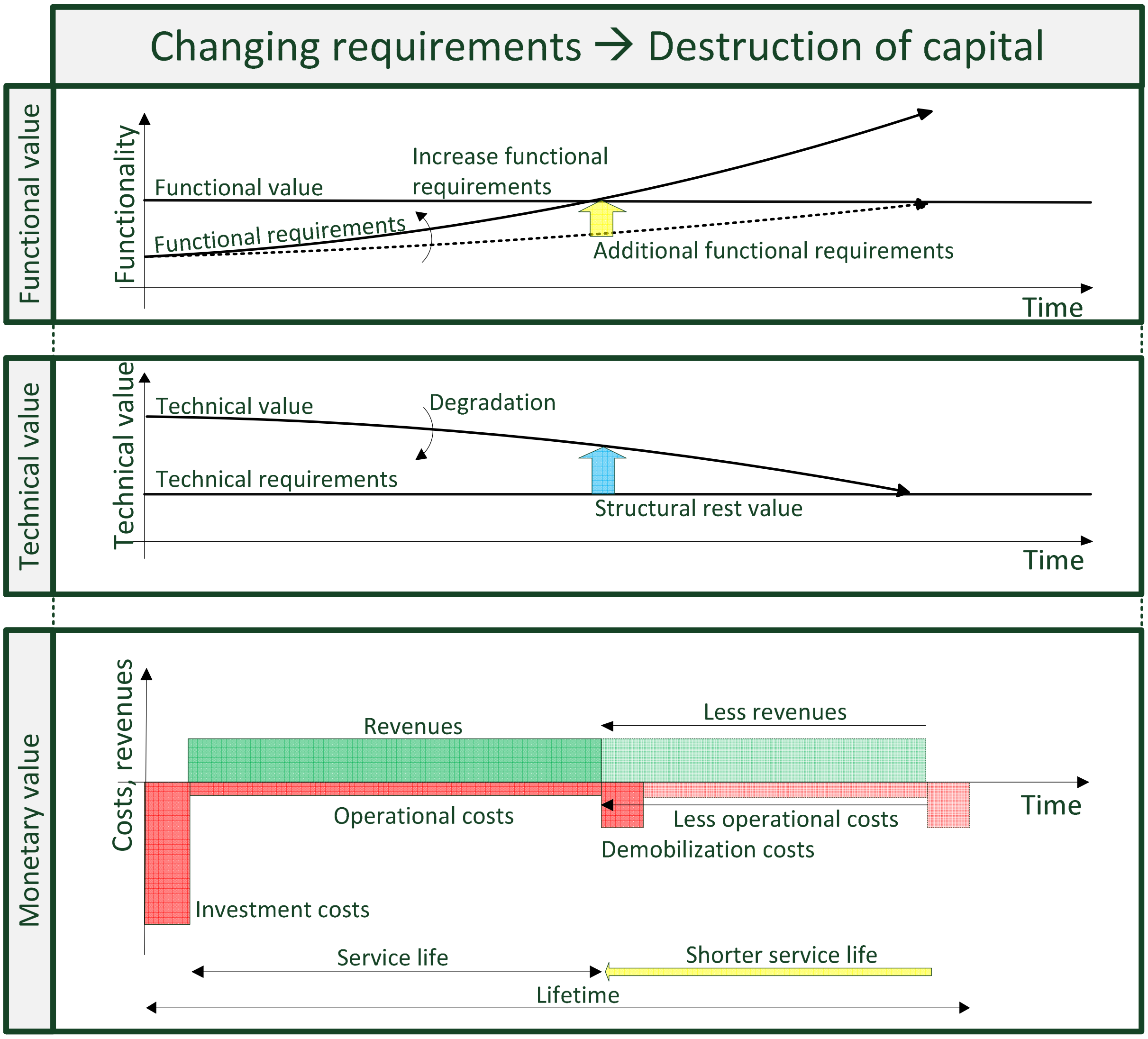


Figure 7-3: Changing requirements → Destruction of capital; (top) increase functional requirements, (middle) decrease technical value plus rest value and (bottom) shorter service life means less costs & revenues

Structural concepts

Port of Rotterdam Authority could improve its profitability by adapting its port infrastructure to match the increase in functional requirements. Three structural concepts are proposed that cope with a fast change in functional requirements *(see Figure 7-4):*

- Robust structures try to cope with the faster changing requirements through a larger functional value *(see Figure 7-4, left).* Larger investments increase the lifetime of the structure, but not necessarily its service life. The inner lake is available for about a decade. Robust structure cannot be relocated and are not suitable for this location.
- Single use structure take the decrease in service life for granted and lower their technical value (see *Figure 7-4*, middle). Smaller investment costs decrease the structure's lifetime and might balance with a shorter period of revenues.
- Flexible structures take the bandwidth of functional requirements into account and can increase their functional value, either at their original location, or at another location *(see Figure 7-4, right).* Larger additional operational and demobilization costs could balance with additional revenues, if not the structure can be sold or downgraded.

Either single use or flexible structural concept could be viable for the inner lake. An analysis of the whole lifecycle costs and revenues indicates the financial viability.

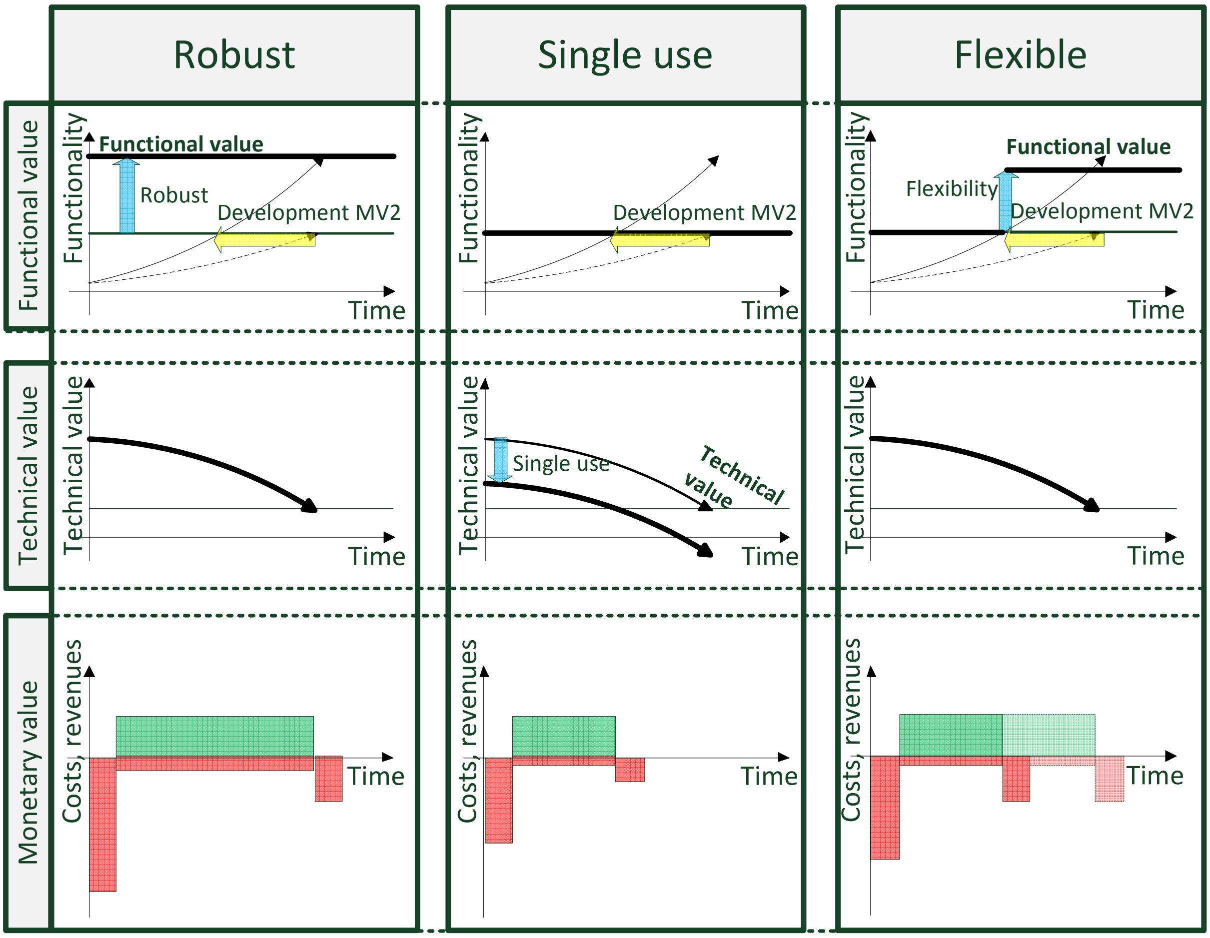


Figure 7-4: Three design concepts to cope with fast changing functional requirements; (left) robust structure: larger initial functional value, (middle) single use structure: lower technical value and (right) flexible structure: option to increase functional value

Lifecycle Analysis
The temporary availability of the inner lake limits the service life to about a decade or so. Most structures have a lifetime of several decades. The structure's lifetime is several times larger than its service life. Some structures have a considerable rest value *(see Figure 7-3).* Structures with a considerable rest value can be reused in the Port of Rotterdam, sold to another port or serve another purpose.

A lifecycle analysis over the lifetime of the structures, i.e. over several service lives, includes the rest value of each structure. Scenarios are used to illustrate the future state of the structures (reuse, sell or demolition), calculate the rest value and illustrate whether reuse-possibilities have to be considered.

The lifecycle of a structure can be divided into a realization, exploitation and demobilization phase *(see Figure 7-5):*

- In the realization phase investment costs occur. Materials are bought and transformed with equipment and labor to structures *(see Section 7.2.1).*
- In the exploitation phase (additional) revenues and operational costs occur. Revenues consist of port dues, rent and mooring dues. Additional revenues occur if structures serve multiple activities *(see Section 7.2.2).*
- In the demobilization and storage phase demobilization, demolition and sometimes storage costs occur. After their service life, structures can be reused in the Port of Rotterdam, sold to another port, or demolished *(see Section 7.2.3):*
    - o Reused structures start another lifecycle in the Port of Rotterdam.
    - o Sold structures generate revenues depending on the structure's rest value.
    - o Demolition occurs, if the rest value is low or no other applications exist.

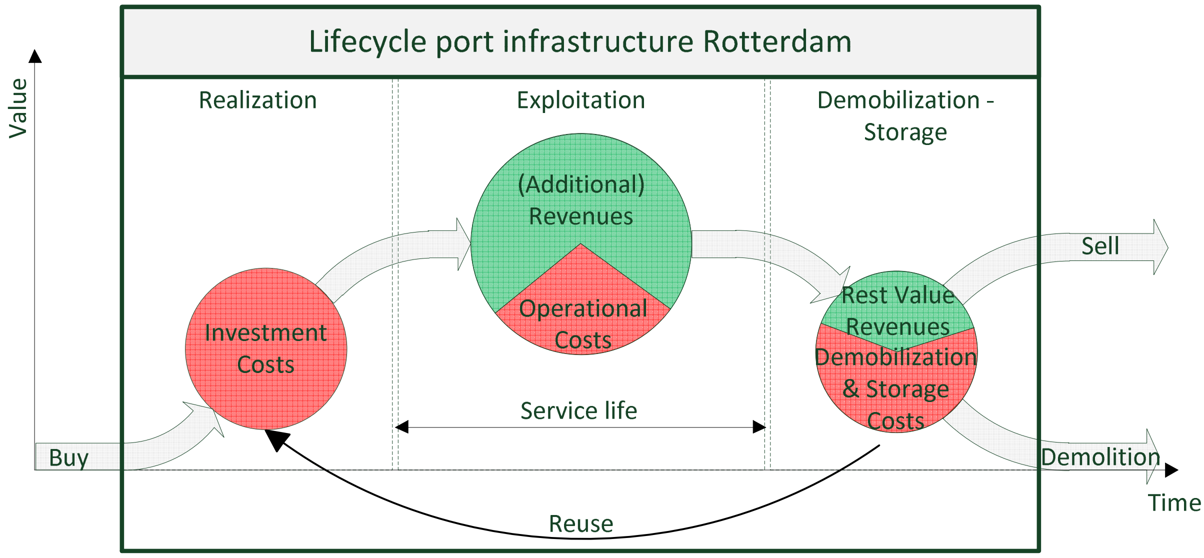


Figure 7-5: Lifecycle phases of port infrastructure; (left) investing in the realization of a structure, (middle) generating revenues and pay operational costs and (right) demobilizing the structure and make use of its rest value: sell, demolition, reuse

7.2 Lifecycle phases

7.2.1 Realization

Time

The realization time of a structure comprises a permit phase, an engineering phase and a construction phase. The duration of the permit and the engineering phase mainly depend on institutional and organizational aspects. Usually both are about the same for structures of similar dimensions. The construction time depends primarily on the equipment and can differ considerably for structures of similar dimensions.

Large elements are usually constructed for specific purposes at dedicated sites and have long construction times. Serial production can sharply decrease the construction time of many elements, but less of an individual element, as there are always several critical steps involved. The construction time of a barge, caisson and very large floating structure of 300 m length is about one year. An L wall and Maxisteck with the same length require about three quarter of a year. Containerland, a sheet pile wall of 300 m and a jetty for sea going vessels require about one quarter of a year [55]. The assembling time of structural components is shorter than that. Structural components can be assembled at site in a couple of weeks [55].

Costs

The investment costs can be estimated with key figures of reference projects or with unit prices, quantities, transport and overhead factors. Contractors use key figures based on previous projects to estimate investment costs. Each contractor calculates its key figures with different projects and keeps them as company secret. Therefore cost estimations can differ considerably for similar projects. This research wants to compare structures in a similar way. Investment costs are estimated with unit prices, quantities, transport and overhead factors:

- The material costs are determined per structure by multiplying unit prices with the quantities *(see Appendix B.1).* It is assumed that a buoy costs about 75,000 €/piece, concrete 500 €/m^3, second hand coated containers 500 €/piece, sand 5 €/m^3, steel 1,500 €/t, stones & granulates 35 €/m^3 and supra structures 2,500 €/m. These unit prices are at site prices for regular elements [42].
- The construction costs include transport costs. Large prefabricated components require special transport equipment [33]. The material costs of a barge, caisson, very large floating structure and L wall are multiplied with transport factor of 1.25. The material costs of the other structures are multiplied with a transport factor of 1 [42].
- The investment costs include risks and profits. The construction costs of all structures are multiplied with an overhead factor of 1.6 [42].

Structures that consist of large prefabricated components have considerably larger investment costs than structures that consist of smaller components. A jetty on a natural slope of 1/10 has larger investment costs than a jetty on with a slope with facing of 1/4. Buoys have larger investment costs than dolphins *(see Figure 7-6 and per component see Appendix B.2).* Usually preliminary investment cost estimations have an accuracy of about 30% [33]. The investment costs that have been estimated for the structures in this research are compared with key figures, generated with hundreds of reference projects [19]. The difference is for each structure smaller than 30% *(see Appendix B.2).*

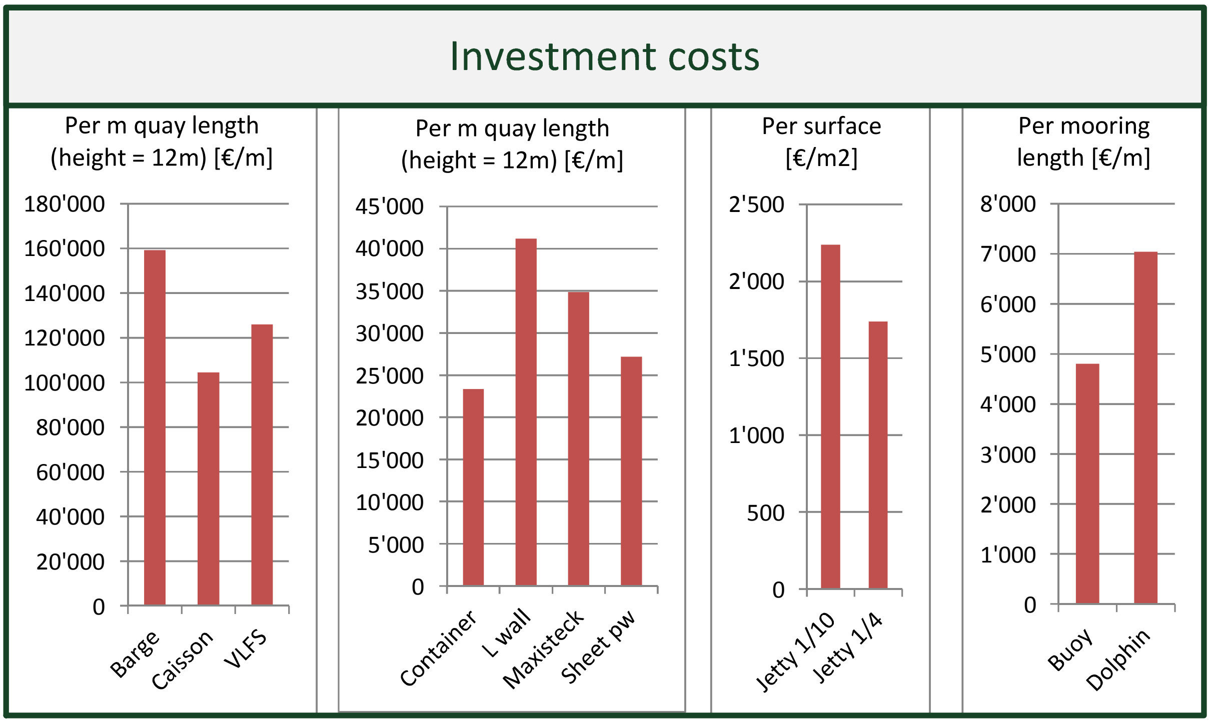


Figure 7-6: The investment costs for the quay type structure per 50 m length determined by unit prices and quantities

7.2.2 Exploitation

Time

The service life of the alternatives the inner lake depends on development of Maasvlakte 2. The average expected availability amounts 7 years. Alternatives are only allocated on sites that remain idle for at least two years and get contracts with cancellation periods of about 1 or 2 years, without any financial obligations [58]. The uncertainty in availability and the strict requirements have a considerable impact on the net present value of each alternative.

Costs

The technical value of a structure decreases due to user loads, environmental loads and disintegration, such as corrosion. Inspection and maintenance evaluate the degradation from time to time. If required the structural value can be improved. Inspection and maintenance costs are usually calculated as a yearly percentage from the investment costs. This percentage varies between 0.5 and 1.5% [19]. 1% is assumed for this research.

Revenues

The revenues of Port of Rotterdam Authority consist of port dues, rent and mooring dues. They are calculated by multiplying unit prices *(this chapter)* with quantities (*see Appendix A.3)*:

- The port dues cover mainly the use of the nautical port infrastructure. The largest part of the port dues is paid by seagoing vessels and is related to the transshipped quantity. Most inland vessels have annual contracts and pay a relatively small amount irrespectively of the number and duration of calls. A shipping company can calculate the port dues that apply to each vessel with the port tariffs, as listed in the general terms and conditions of Port of Rotterdam Authority. Port tariffs are calculated with the switch percentage, cargo rate, gross tonnage tariff and gross tonnage size of a vessel [47]. The calculation of the port dues with the port tariffs is cumbersome. Not all shipping companies obtain the same discounts. Moreover they rather use the vessel's dead weight tonnage (DWT) than vessel's gross tonnage to indicate the vessel's size. Port of Rotterdam Authority publishes its total port dues revenues [41] and throughput per year [54]. This information can be used to calculate the average port dues transshipped quantity, i.e. 0.65 €/t (total revenues port dues in 2010 / total throughput in 2010 = 288 M€ / 430 Mt). This number differs at most 25% with key figures of various cargo types [42] [49].

- The rent covers mainly the use of landside infrastructure. The average rent is calculated with the total rent [41] and rented sites [54], i.e. 5.21 €/m^2 (total revenues rent in 2010 / total surface rented in 2010 = 249 M€ / 48 Mm^2). This number can differ from site to site with several 100% [55].
- The mooring dues are included in the rent, but represent only a very small part [42]. They can be retrieved from general terms and conditions of Port of Rotterdam Authority and can be calculated per vessel size. A vessel pays 2.92 €/LOA/d for a mooring dolphin and 2.66 €/LOA/d for a mooring buoy [47].

Liquid bulk transshipment has revenues larger than 1 M€. A common barge terminal, dry bulk storage, wind energy and wind turbine assembling have revenues of a couple of 100 K€. Other activities have revenues of a couple 10 K€ or zero *(see Figure 7-7)*.

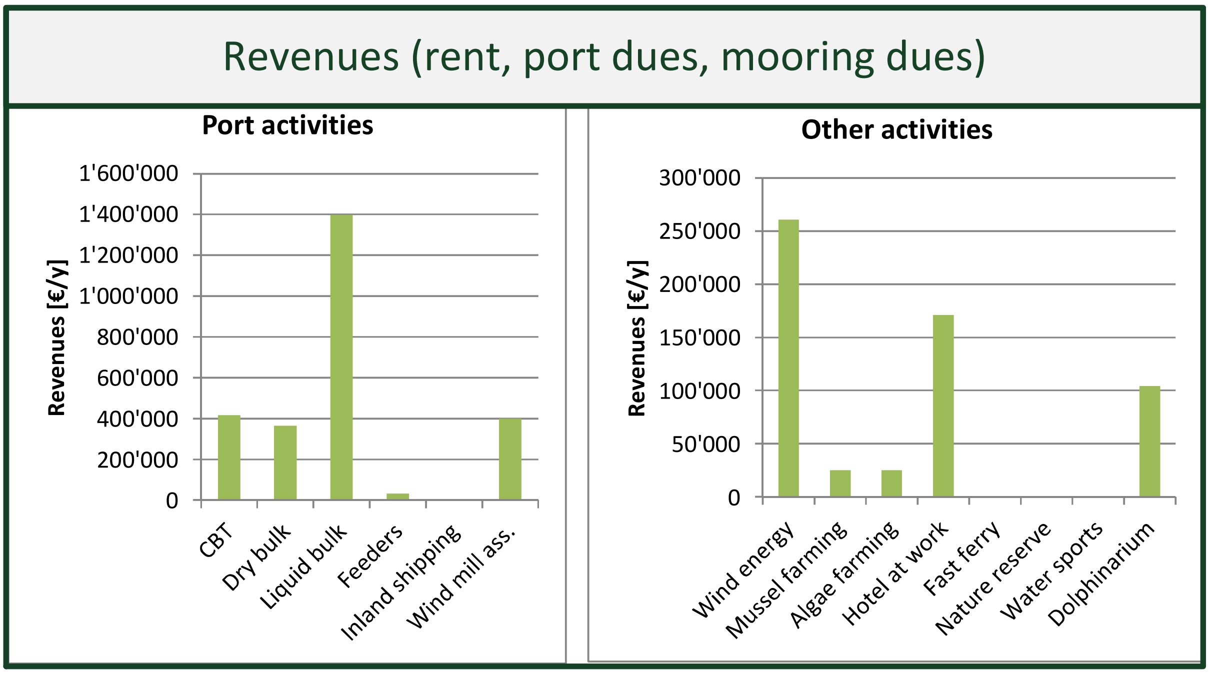


Figure 7-7: Revenues per activity based on actual market conditions, these may not apply for an innovative concept *(revenues per rent, port dues and mooring dues see Appendix A.3, net cost savings CBT see Section 6.3)*

- Some structures have shorter realization times than others and enable activities to generate revenues earlier. These revenues are calculated by multiplying the difference in realization time *(see Section 7.2.1)* with the total revenues *(see Figure 7-7).*

- The additional revenues are used in case the structures are reused in the Port of Rotterdam, i.e. for a second or third service life: They are estimated with the total port dues over the total quay length in the Port of Rotterdam [57], i.e. 3,200 €/m (total port dues in 2010 / quay length in 2010 = 288 M€ / 90 km).

7.2.3 Demobilization – Storage

Time
Structures have to be relocated from the inner lake after their service life. The disassembling of the structures can be done in several months. The transport time depends mainly on the distance and lasts at most several weeks [55]. Structures can also be stored for some months or years until a new activity has been found.

Costs
Demolition costs occur, in case no new application is found and demobilization costs, in case a new application is found. If the structure is not reused directly after its service life, storage costs occur additionally. After storage demobilization costs have to be paid again.

- Demolition costs are usually expressed as a percentage of the investment costs. 17.5% is used for structures that are downgraded and sold to raw materials [19].
- Demobilization costs are calculated in a similar way. It is assumed that 25% of the investment costs have to be paid to disassemble, transport and assemble a structure at another location.
- Storage costs depend on the lease fees and required surface. It is assumed that the lease fees are equal to the average rent, i.e. 5.21 €/m2. Furthermore it is assumed that the required surface has a length that equals the quay length and a width of 50 m.

Revenues
Port of Rotterdam Authority has to sell the structure, in case no new application can be found in the Port of Rotterdam. The rest value revenues vary somewhere between the structure's rest value and raw material prices. It can be estimated by subtracting the demobilization costs and degradation of the structure from the investment costs:

- ➢ Rest value revenues = Investment costs – degradation – demobilization costs

- The structure's value downgrades at most linearly in the first half of the structure's lifetime. The structure's value usually declines slightly at the beginning and more steeply at the end of its lifetime [33]. Furthermore port infrastructure is, contrary to most consumer goods, barely affected by changes in emotional values.
- The investment costs are more or less the same over the past years in the Hamburg – Le Havre range. A quay wall with a retaining height of 20 m costs in France, Belgium, the Netherlands and Germany about 30,000 € per quay length [19].

Reuse-possibilities
Structures can initiate a new service life in the Port of Rotterdam or elsewhere, directly after their service life or after a while. Some structures can be reused completely as port infrastructure, or as components in other applications, others have to be downgraded to an elementary scale and reused as raw materials *(see Table 7-1)*.

Maintaining the value of a structure and keeping the structure at its original location is always preferred from an ecological point of view. The reuse-possibilities depend on the number of port infrastructure projects and the match between the characteristics of the structure, requirements of the customer and the site conditions. The most important structural characteristics are its remaining service life, retaining height, connections and bearing capacity:

- The number of port infrastructure projects in about 10 years depends on the economic growth. The throughput of containers in the Port of Rotterdam increases in 20 years to come in the worst economic scenario with 3.5% and on average with 5.74% [53]. From 2010 to 2035 inland shipping will increase on average with 5.6 MTEU [53]. This implies that, with a quay capacity of 800 TEU/m/y, about 280 m/y quay has to be constructed in the hinterland in the next 25 years. This assumption is rather conservative:
  - The modal shift will change in favor of inland shipping from 39% (2011) to 43% (2030) [53].
  - More efficient unloading systems, such double decks, are very expensive [33]. If they are financially viable, they will be applied at deep sea quays first.
- The remaining service life of a structure can depend on the shortest lifetime of its components. A structure consists of several components. Replacing a component just after the inauguration of an activity is awkward.
- The retaining height of a port infrastructure reaches from bed to the ground level and determines the maximum draft at the quay. Flexible structures can adjust their retaining height by removing, rotating, or adding components (see *Table 7-1*).
- The connection with the shore determines whether additional structures are required. A sheet pile wall, L wall, caisson and Maxisteck fit to any slope. Containerland, barge and structures based on very large floating structure concepts are more suitable at existing quays.
- The connections between the components determine together with the availability of the components the assembling time. Serial produced and standardized components, such as containers, have a higher availability. Floating structures are only connected to the shore via bridges and mooring facilities. They have very short assembling times and can adjust their freeboard through more or less ballast. Flexible connections ease the assembling, but can worsen the workability and stability.
- The bearing capacity of a port infrastructure determines maximum weight of the equipment and cargo on the quay. The dimensions of the components determine the bearing capacity. Larger components can usually bear larger loads, but not always transfer loads directly to the subsoil. Large loads have to be spread on soft soils either horizontally with rubble and filter layers, or vertically with piles.

Structures can be designed with various dimensions for dedicated or multiple purposes. An overview table with some reuse-possibilities indicates how structures can be used after their service life and what their dimensions ought to be *(see Table 7-1).* Dimensions and weights of the components determine the required assembling equipment. It is expected that more (heavy) lift equipment will be available in the upcoming years [16].

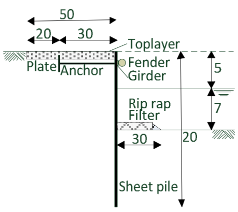
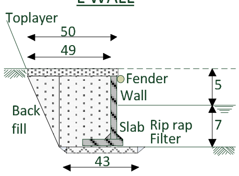
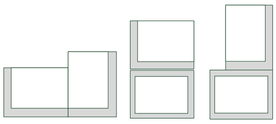
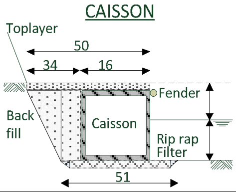
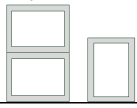
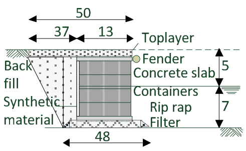
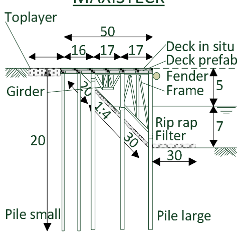
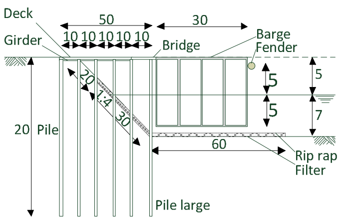
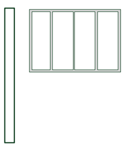
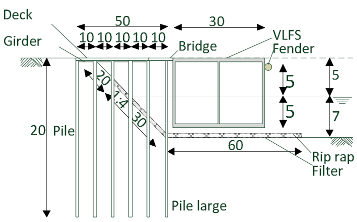
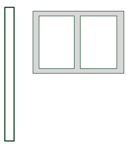
Reuse-possibilities structures			
Image	**Characteristics**	**Port infrastructure**	**Other**
SHEET PILE WALL 	- Soft soil,several heights - rh=20-30 m, tl=25 y		- Sheet pile in construction pit
L WALL 	- No soft soil, 2 heights - rh=5-15 m, tl=50 y 	- L wall as foundation crane	- L wall as abutment - L wall as dry bulk storage
CAISSON 	- No soft soil, 3 heights - rh=10-30 m, tl=50 y - q=40-100 kN/m2 	- Caisson in deep sea quay wall - Caisson for liquid bulk storage	- Caisson as closure dam - Caisson as breakwater - Caisson for foundation wind mill
CONTAINERLAND 	- Any soil, several heights - h=5-15 m, tl=10,50 y - q=40 kN/m2 	- Slabs in crane track - Slabs terminal road	- Slabs in buildings
MAXISTECK 	- No rock, several heights - h=5-30 m, tl=25 y 	- Jetty for liquid bulk transshipment - Piles as dolphin - Pile foundation	
BARGE 	- Any soil, ballast level - d=5-10 m, tl=25y 	- Jetty for liquid bulk transshipment - Barge as floating storage - Piles as dolphin - Pile foundation	- Barge as foundation floating: - Road - Offices - Houses - Stage
VLFS 	- Any soil, ballast level - d=5-10 m, tl=50y 	- Jetty for liquid bulk transshipment - VLFS as floating storage - Piles as dolphin - Pile foundation	- VLFS as foundation floating: - Road - Offices - Houses - Stage

Table 7-1: Reuse possibilities structures, (1st column) image, (2nd column) characteristics, (3rd column) reuse-possibilities in port and (4th column) reuse-possibilities elsewhere

7.3 Net present value

7.3.1 Principle

Net present value
The financial viability of each alternative is determined by its whole lifecycle costs and revenues. The value of costs and revenues decreases over time for several reasons. First, inflation increases the amount of money per product. Second, receiving money now is certain. Third, putting money to work can accumulate its value [67].

The present value of past and future costs and revenues is usually determined with a discount rate. It reduces future costs and revenues are reduced each year by certain factor and increases past costs and revenues each year by a certain factor. The sum of the discounted costs and revenues is called net present value. The net present value enables to compare alternatives with different costs and revenues over time at a basic year.

Discount rate
Investors use different discount rates based on their portfolio. Governments have a large portfolio, many assets and can borrow money at low interest rates. The Dutch government uses a discount rate between 4 and 5% [55]. Companies have a smaller, more risky portfolio, fewer assets and have to borrow money at larger interest rates. They are beyond that more profit driven and use discount rates between 12 and 13% [42]. Port of Rotterdam Authority is a private company with the Dutch government and Municipality of Rotterdam as main shareholders [57]. Its discount rate varies somewhere between 4.5 and 12.5%:

- A high discount rate is not required and renders many initiatives not viable. Port of Rotterdam Authority can borrow money at moderate interest rates [42].
- A low discount rate is not possible. Port of Rotterdam Authority uses the discount rate to redistribute its revenues. Some projects of Port of Rotterdam Authority generate revenues themselves, others do not. Port dues and rent are related to quay walls, not to waterways. However, waterways are required, in order to let quay walls function. Quay walls have to generate enough revenues to cover their own investment costs and the investment costs of waterways [42].

Uncertainty
The net present value can be calculated with the future costs and revenues as one number. However, in reality it is very unlikely that the actual net present value will achieve this value. Future costs and revenues are estimations and subjected to changes. The net present value can be higher or lower than expected. A risk analysis quantifies the variation of the input parameters and generates with a simulation (e.g. Monte Carlo) an expected net present value and a value at risk [62]. The expected net present value represents the average net present value and the value at risk a lower limit of many net present value simulations. A quantitative risk analysis identifies explicitly the probability of a certain net present value, but involves a large amount of calculations [67].

➢ Another way to evaluate the bandwidth of a net present value is to build scenarios and vary certain key parameters.

Scenarios
Future states can be described with scenarios *(see Figure 7-8)* [67]. It is assumed that the first service life on the inner lake lasts 10 years. Structures can be demolished (scenario 1), sold to another port (scenario 2), or reused in the Port of Rotterdam in 2024. It is assumed that the second service life in the Port of Rotterdam or its affiliated ports lasts 15 years. After the second service life structures can be demolished (scenario 3), sold (scenario 4) or reused once more (scenario 5). It is assumed that before third service life of 20 years starts that an intermediate storage of 5 years takes place.

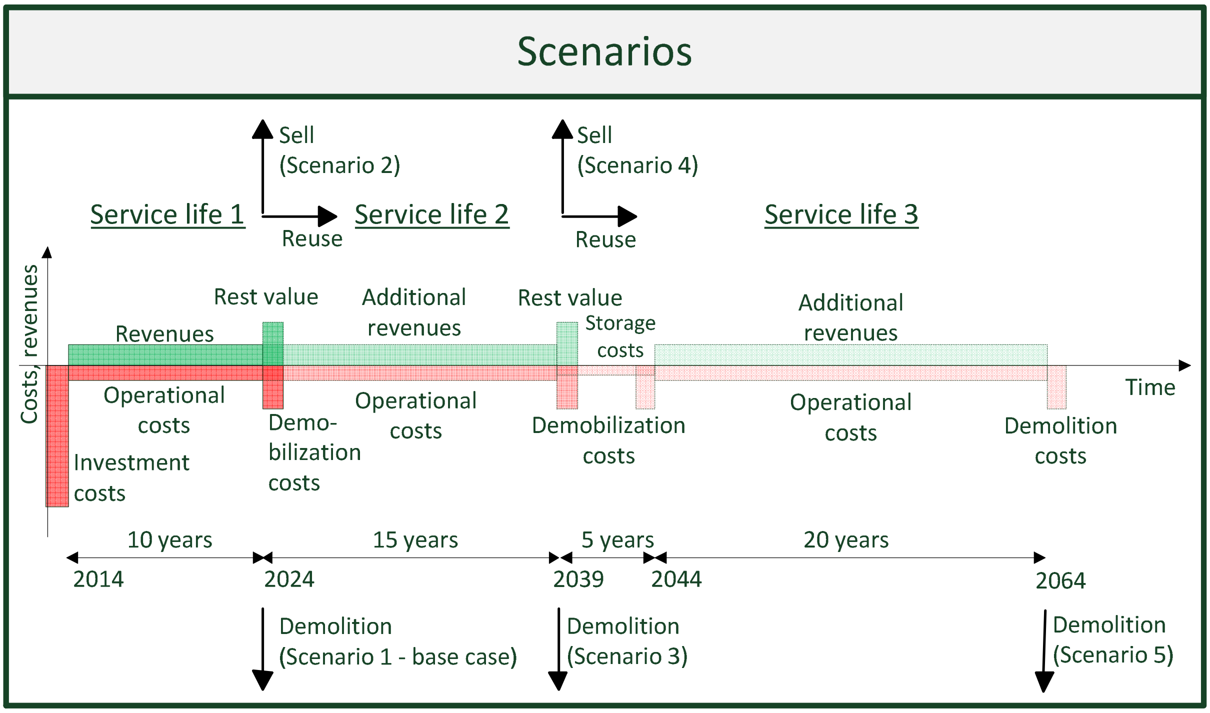


Figure 7-8: Five scenarios in order to determine the bandwidth of the net present value of the alternatives

Sensitivity
The variation on future states can be determined by varying key parameters. The choice of the parameters and their values is always somewhat subjective [62]. This research takes low, medium and high value for the service life (5, 10 and 15 years) on the inner lake and the discount rate (4.5, 8.5 and 12.5%):

- The dimensions and unit prices of activities and structures are estimated with literature and expert opinions. Most values are based on several reference projects. First, these parameters are not the most subjected ones to change. Second, the variation of these parameters requires an adjustment of many other parameters as well.
- The numbers of activities (e.g. calls per year) and novel parameters (e.g. replacement costs percentage) are estimated as best guess. These parameters are highly subjected to changes. However, they do not concern all alternatives. A variation of these parameters is useful after the alternatives pass the preliminary design stage.
- The discount rate and service life are the only parameters that influence almost all cost and revenue components of all alternatives *(see Figure 7-8)*. The variation of one parameter influences all alternatives.

7.3.2 Results

Net present value structures
Alternatives consist of activities and structures. An activity has to be coupled with the structure with the lowest whole lifecycle costs. Many combinations of activities, structures and input parameters can be examined. This research determines the structures' whole lifecycle costs with one activity and one set of input parameters for five scenarios:

- The examination of all combinations results in a large number of calculations.
- The influence of the activities on the whole lifecycle costs is small. The differences in retaining height and bearing capacity determining investment costs are relatively small.
- The largest differences in net present value depend for most structure on the type, not on the variation of the input parameter *(see Section 7.3.1).*

A common barge terminal, wind turbine assembling facility and dolphinarium require a quay. The whole lifecycle costs are determined for a common barge terminal *(see Figure 7-9).*

- ➢ Modular structures have lower whole lifecycle costs than large prefabricated structures: The net present value of a common barge terminal using Containerland is positive and using a barge is negative after 50 years.
- ➢ Structures with single use components have lower whole lifecycle costs than structures with multiple use components: The net present value of a common barge terminal using Containerland is some hundreds of thousand euros larger than using a sheet pile wall at every moment in time *(see Figure B-14).* This research choses Containerland.

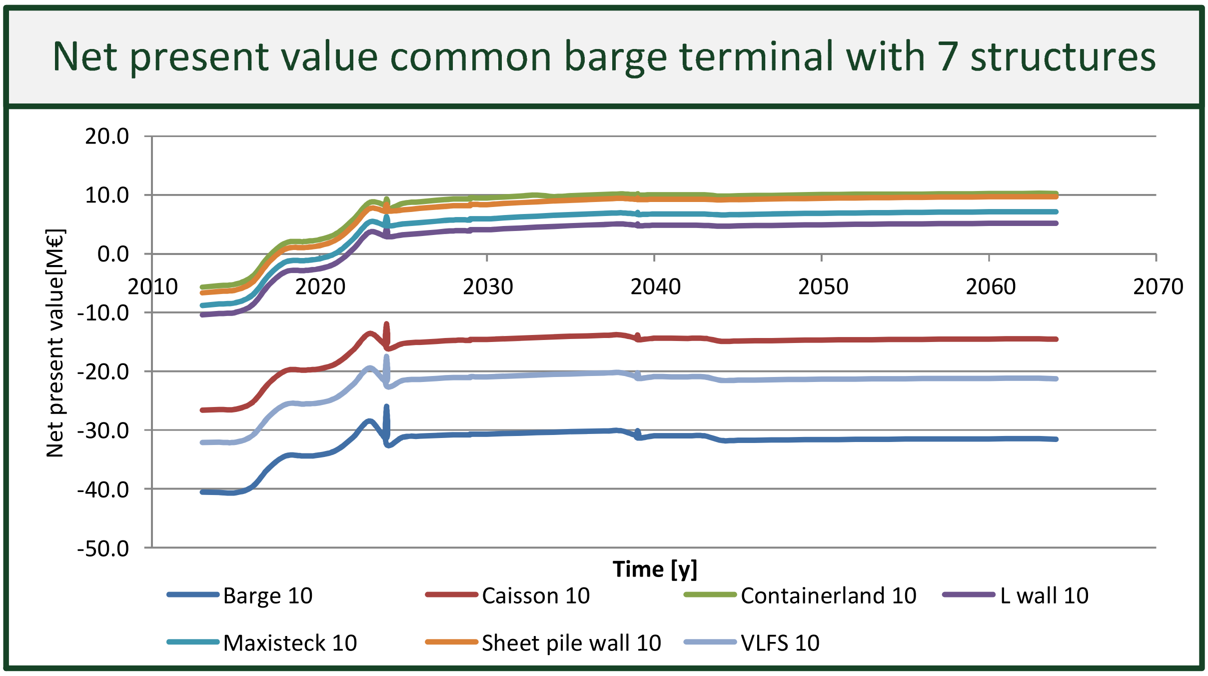


Figure 7-9: Net present value common barge terminal with 7 structures; the spikes at 2024 and 2039 represent the net present values of the different scenarios (largest net present value = sell, smallest net present value = demolition)

Liquid bulk transshipment, feeders and inland shipping require a mooring structure. The whole lifecycle costs are determined for liquid bulk transshipment *(see Figure B-14):*

- Dolphins have slightly larger whole lifecycle costs than buoys. Port of Rotterdam Authority prefers dolphins over buoys. Vessels moored at dolphins have smaller displacements and can discharge a larger throughput *(see Section 5.1.2).* This research chooses a dolphin.

Hotel at work and the fast ferry require a jetty. The whole lifecycle costs of two jetties are determined for hotel at work *(see Figure B-14):*

- A long jetty on a natural slope of 1 over 10 has larger whole lifecycle costs than a short jetty on a slope of 1 over 4 with a facing. This research chooses a short jetty.

Net present value alternatives

Now, the net present values of all alternatives are determined with the chosen structures. Some alternatives do not require any structures from Port of Rotterdam Authority. Their net present values are calculated over the service life of the inner lake, i.e. 10 years. The net present values of alternatives that do require structures are calculated for all scenarios over lifetime of the structures, i.e. 50 years.

All alternatives that do not require a structure by Port of Rotterdam Authority are financial viable *(see Figure 7-10).* Their net present values are also larger than zero for different discount rates *(see Appendix A.4).*

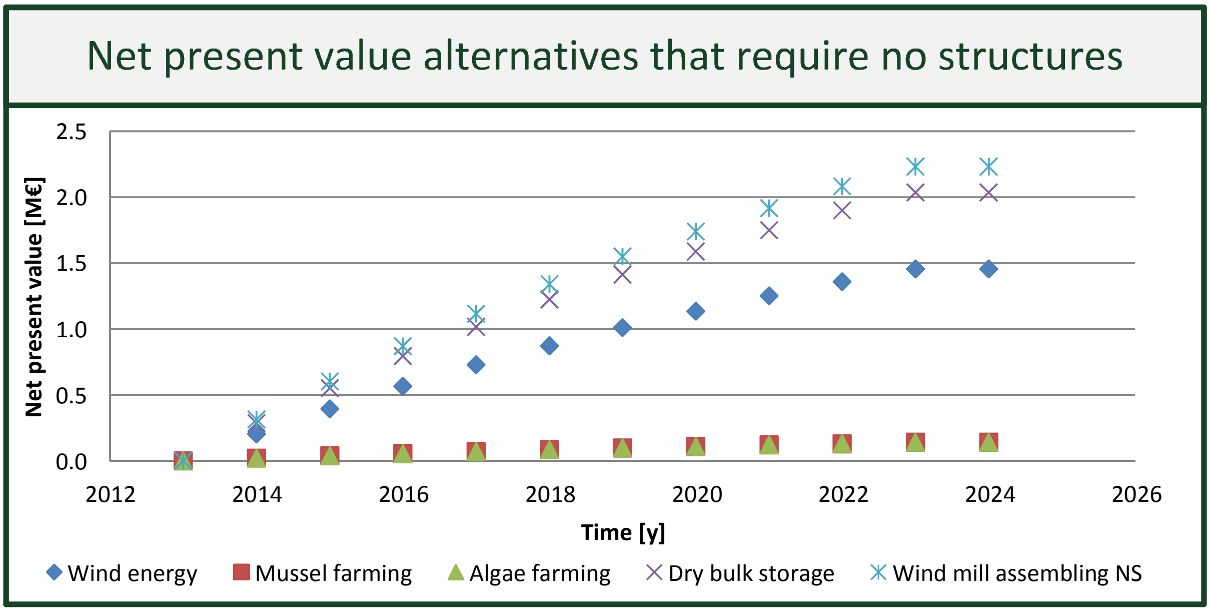


Figure 7-10: Net present value of alternatives that do not require structures from Port of Rotterdam Authority over 10 years with a discount rate of 8.5%

Some alternatives that require structures are financial viable, others not *(see Figure 7-11)*. The common barge terminal, liquid bulk transshipment and hotel at work already have a positive net present value within their first 10 years. A dolphinarium, fast ferry and wind turbine assembling facility with dedicated quay do not even attain a positive net present value after 50 years. Mooring spaces for inland shipping and feeders are financial viable from their second service life, as it is assumed that the dolphins generate additional revenues.

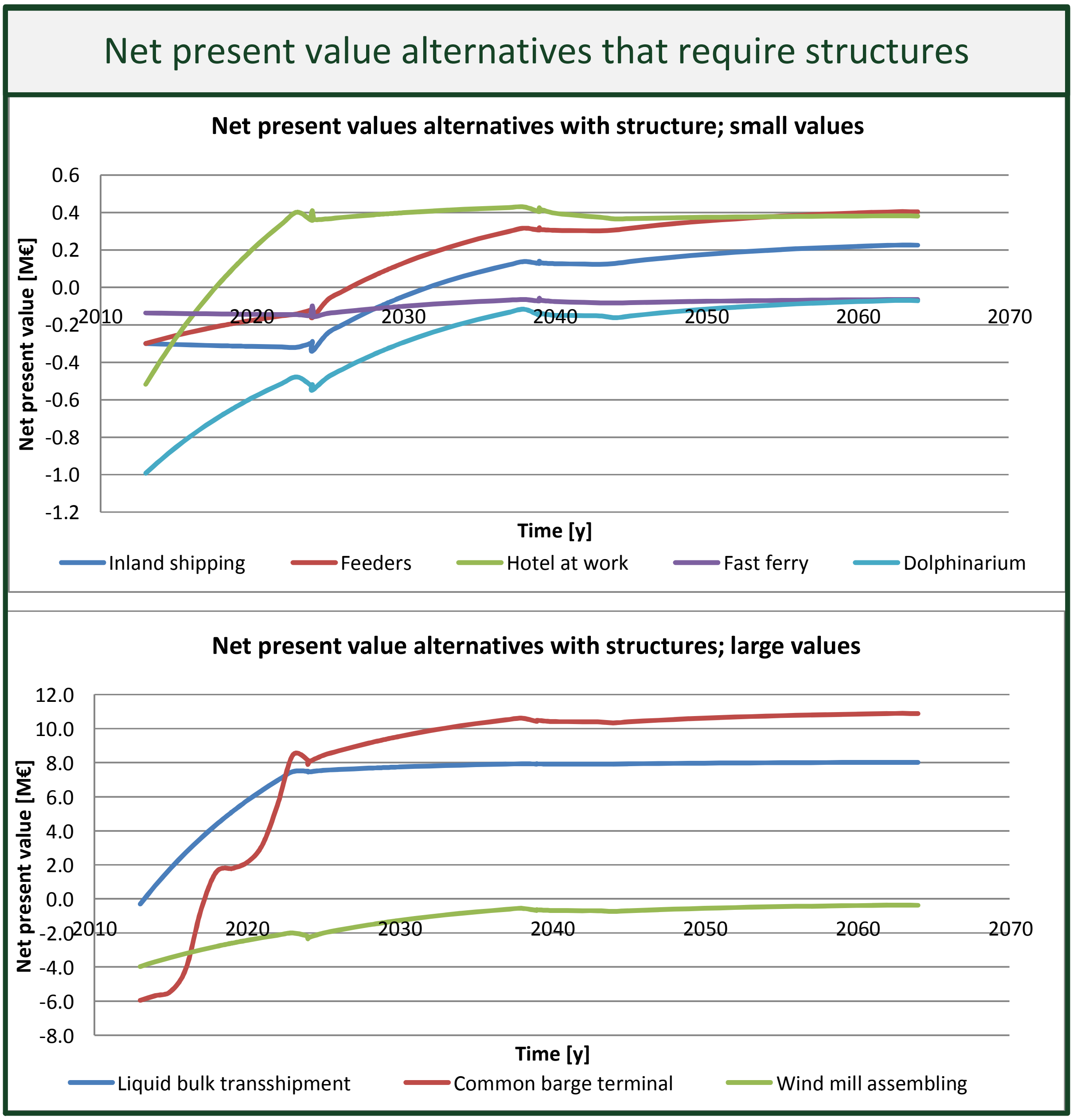


Figure 7-11: Net present value of alternatives that require structures over 50 years with service life inner lake of 10 years and discount rate of 8.5% for all scenarios (calculated per year, illustrated continuously for visibility reasons)

The net present values of alternatives vary over time *(see Figure 7-11)*. Only the net present values of the alternatives that require a quay rise considerably after the service life on the lake, i.e. after 2024. The rest value of a common barge terminal after 2024 is evaluated against the net present value until 2024 next.

Rest value
Scenarios specified different future states of the structures *(see Figure 7-8)*. Some scenarios result in larger net present values than others. A base case is used to evaluate the potential benefits and losses of the scenarios against each other [64]. This research takes the first scenario, i.e. demolition after service life on the inner lake, as base case. The net present values of other scenarios are evaluated against the base case. The rest value represents the additional net present value and indicates whether reuse-possibilities have to be considered *(see Table 7-1).*

Business case common barge terminal
The net present value of a common barge terminal using Containerland is calculated by adding the net present cost savings *(see Section 6.3)* to the net present costs and revenues of the lifecycle phases *(see Section 7.2).* The net present is 8 M€ in case Containerland is demolished after its service life (base case) and 11 M€ in case Containerland is reused twice *(see Figure 7-12)*. Port of Rotterdam Authority can generate a rest value of about 3 M€ or 40%. The net present values depend on various parameters.

The rest value increases for shorter service lives and smaller discount rates. The net present value of the base is 1 M€ and of the reuse scenario is 6 M€ in case the service life of the inner lake is 5 instead of 10 years. Port of Rotterdam Authority can generate a rest value of 5 M€ or about 500%. The net present value of the base is -1 M€ and of the reuse scenario is 6 M€ in case the discount rate is 4.5% instead of 8.5%. Port of Rotterdam Authority should realize a common barge terminal in case Containerland is reused twice and not realize in case Containerland is demolished after its service life on the inner lake. The variation of input parameters of other alternatives give similar results *(see Appendix B.2).*

- Reuse-possibilities have to be considered until a service life of 10 years and until a discount rate of 8.5%

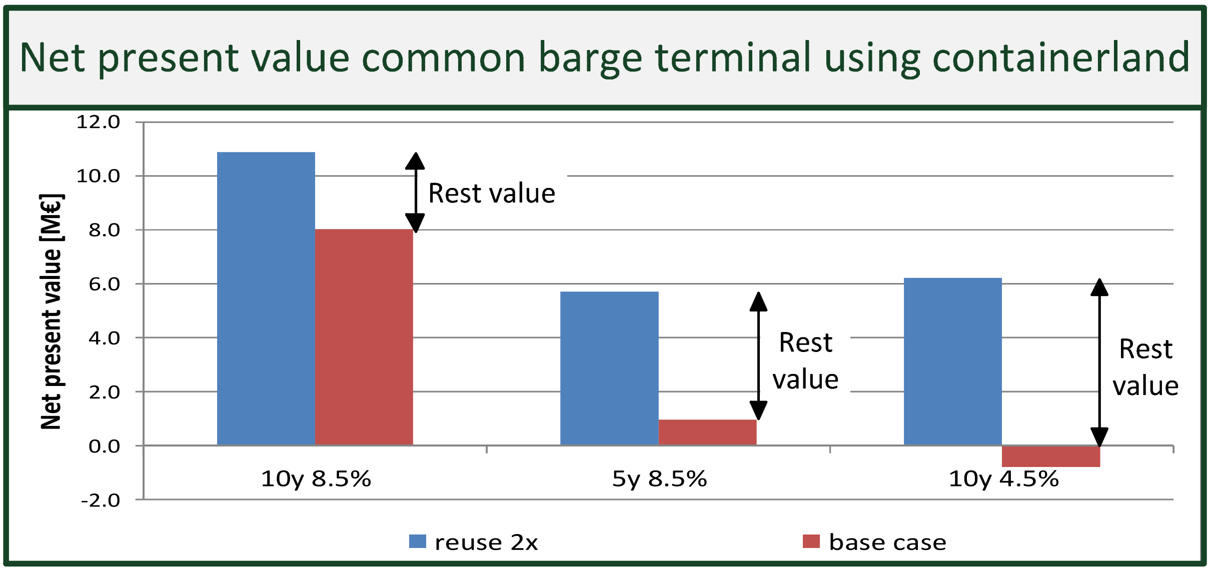


Figure 7-12: Business case Port of Rotterdam Authority common barge terminal with contanerland; base case and reuse 2x for different parameters; (left) service life 10 years, discount rate 8.5%, (middle) service life 5 years and (right) discount rate 4.5%

7.4 Conclusions

This chapter determined the financial viability of each alternative. A lifecycle analysis identified all costs and revenues per lifecycle phase, i.e. realization, exploitation, demobilization. The net present value cumulates the discounted costs and revenues. It is used to compare alternatives with different costs and revenues over time.

The service life of the inner lake is shorter than the lifetime of the structures. This means that structures have a rest value. Port of Rotterdam Authority can reuse the structures as raw material, as components in other structure, as complete structures in its own ports or sell them to other ports. The reuse-possibilities depend on the characteristics of the structure, number of port infrastructure projects, customer's requirements and site conditions.

Scenarios define the structures' future state. Structures can be demolished, sold or reused after their service life. Structure can be reused once or twice, until their lifetime finishes, i.e. no rest value. A sensitivity analysis defines the variation of the future state. Low, medium and high values are assumed for the discount rate and service life. The scenarios and sensitivity analysis determine the bandwidth of the net present value. The rest value measures the difference in net present values and indicates whether reuse-possibilities have to be considered. The largest net present value is achieved when reusing a structure twice.

1) Structures that result in the largest net present value have the lowest whole lifecycle e costs. All scenarios and medium input parameter are used:
   a) Large prefabricated structures, i.e. barge, caisson, very large floating structure and L wall, have larger whole lifecycle costs than (semi) modular structures, i.e. Maxisteck, sheet pile wall and Containerland.
   b) Structures with single use components, i.e. Containerland, have smaller whole lifecycle costs than structures with multiple use structures, i.e. all other structures.
   c) A jetty on 1/10 slope has larger whole lifecycle costs than a 1/4 slope with facing.
   d) Dolphins have slightly larger whole lifecycle costs than buoys, but are preferred by Port of Rotterdam Authority. They have smaller displacements.

2) The net present values of the alternatives are calculated with five scenarios.
   a) All alternatives that do not require a structure are financial viable.
   b) A common barge terminal, liquid bulk transshipment and hotel at work already have a positive net present value within their first 10 years.
   c) A dolphinarium, fast ferry and wind turbine assembling facility with dedicated quay do not even attain a positive net present value after 50 years.
   d) Inland shipping and feeders are financial viable from their second service life.

3) The net present values are calculated with all scenarios and input parameters. For the common barge terminal using Containerland it is calculated that:
   a) Port of Rotterdam Authority can generate a rest value of 3 M€ or about 40% in case the service life is 10 years and the discount rate is 8.5%.
   b) Port of Rotterdam Authority can generate an additional net present of 5 M€ or about 500% in case the service life is 5 instead of 10 years.
   c) Port of Rotterdam Authority can generate a positive net present value by reusing the structure twice instead of demolition at a discount rate of 4.5 instead of 8.5%.

8 Evaluation

This chapter describes the added value of the alternatives. Section 8.1 lists four evaluation methods and describes the principle of a balanced score card. Section 8.2 deduces criteria from the port vision, annual report, internal documents and describes the evaluation criteria for this research. Section 8.3 evaluates the alternatives in a balanced score card.

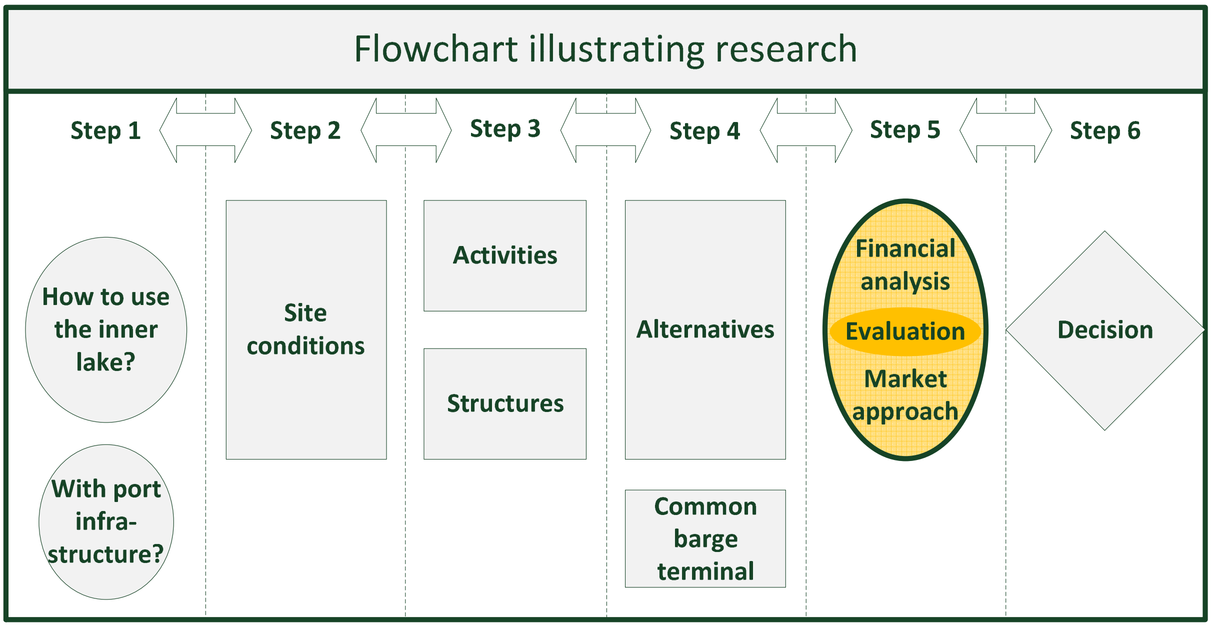


Figure 8-1: Flowchart illustrating research, chapter 8; deduction of evaluation method, criteria and evaluation of alternatives with balanced score card

8.1 Evaluation method

Non-monetary value
The alternatives for the inner lake are not stand alone products, but influence their environment. Non-monetary value is – whether deliberate or not – taken into account.

Decades ago most port customers made direct trade-offs between the costs and added value to their own business. Over the years more port customers became more dependent on each other. Therefore more port customers consider also the added value of a port for their customers, suppliers, employees, and environment. Port of Rotterdam Authority has observed this shift in customer requirements and focuses not only on the port infrastructure, but also on the allocation of the companies, such as production facilities, in the port [57].

About a decade ago companies started to use the environment as well to create added value. Whereas the triple bottom line concept also referred as people, planet, profit persuades customers about the companies' positive environmental impact. Social corporate responsibility sets the companies' ethical standards which could replace existing regulations and even lead to new regulations[71]. Port of Rotterdam Authority wants to increase the generated added value in the Port of Rotterdam even further by improving, besides port infrastructure, also the working and living environment [57].

Evaluation methods
An evaluation can be carried out with different methods. The choice of the evaluation method and criteria depends on the problem, alternatives and data. Evaluation methods handle data in a different way. The effort of the data treatment has to balance out against the benefits of the method [71]. Basically, there are four types of evaluation methods [62]:

- Monetary methods, such as a cost benefit analysis, quantify all data and present the results by numbers. The aggregate approach converts all data of the alternatives in monetary terms. The alternatives of this research have monetary and non-monetary characteristics. Monetary methods suppress some impacts of this research.
- Methods of participation clarify badly formulated problems and present results through interaction with decision makers. The problem of this research is already clearly defined *(see Section 1.2).* Methods of participation are inefficient for this research.
- Multi criteria evaluation methods present the results in a table and take the importance of each criterion into account by a weight matrix. They give insight into different evaluation policies. Port of Rotterdam Authority described its policies already in its port vision. Multi criteria evaluation methods are too cumbersome for this research.
- Methods of overview tables recapitulate most essential information in tables. They present the monetary and non-monetary value of each alternative in a transparent way. An overview table is suitable for this research. The most common overview table method is the balanced score card.

Balanced score card
Companies use a balance score card to align their vision and strategy with their business activities and to monitor their performances. Business activities are managed at different strategic altitudes *(see Figure 8-2, left)*. The mission describes the reason of existence. The vision sketches the companies' picture of the future and indicates significant milestones. Somewhat lower in strategic altitude, the strategy defines the company's game plan. It prescribes how a company approaches its customers and outperforms its competitors [2].

Good strategies alone do not guarantee any success. Strategies have to be incorporated into managerial decisions. Operational managers have different product portfolios and have to cope with different boundary conditions. They take decisions in a different way [26]. Companies use a balance score card to define company-wide critical success factors in four perspectives *(see Figure 8-2, right)* [2]:

- Learning: trace, change and improve the right activities, in order to create value,
- Process: excel the right operations, in order to satisfy customers and shareholders,
- Customer: right appearance to customers, in order to sell products,
- Financial: right appearance to shareholders, in order to raise capital.

Critical success factors focus on actionable components enabling operational managers to evaluate and initiate projects. Initiatives realize a strategic goal for a specific budget. Since the projects' environment changes, it is necessary to evaluate achievements and budget along the way. Key performance indicators measure achievements at a specific moment in time by targets [26].

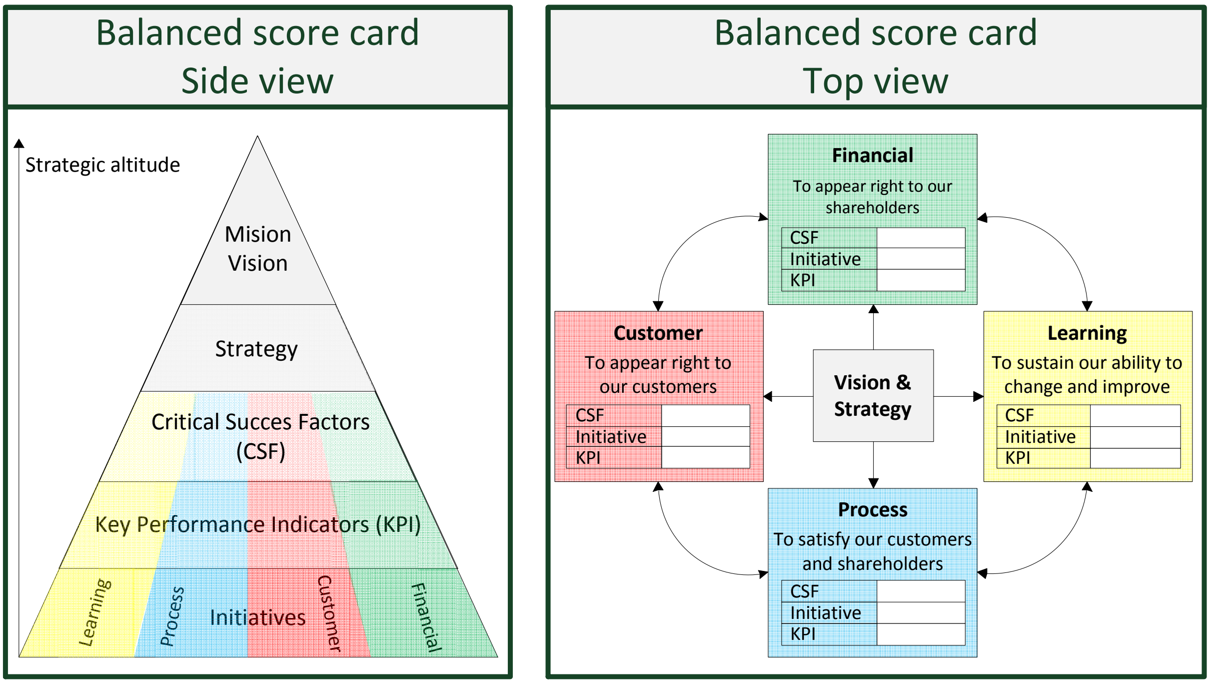


Figure 8-2: Concept of the balanced score card (left) align day to day businesses with vision by critical success factors + key performance indicators [26] and (right) deduction evaluation criteria with four perspectives [2] *(for this research see Table 8-1)*

Port of Rotterdam Authority has defined its vision, strategy, critical success factors and key performance indicators in the Port Compass 2030, its annual report and other internal documents. These documents analyzed the Port of Rotterdam, its environment and described its desired development.

- ➢ Next section translates the criteria of these documents into evaluation criteria for the alternatives on the temporary inner lake.

8.2 Evaluation criteria

8.2.1 Sources of criteria

Port compass 2030
Port of Rotterdam Authority has outlined its vision on the Port of Rotterdam together with various customers and organizations in the port compass. Port of Rotterdam Authority sees the Port of Rotterdam in 2030 as Europe's most important port and industry complex. The realization of the port vision depends on the development of the throughput. Four economic scenarios have been drawned up by the Dutch Bureau for Economic Policy Analysis and the European Commission. Scenarios are translated into throughput estimates. Backcasting and forecasting are used to transform the port vision and throughput estimates into critical success factors. Whereas backcasting creates insight into desirable futures, forecasting identifies opportunities and challenges. Critical success factors draw up specific issues that have to be optimized in order to realize the vision [53].

Efficient land use and environmental thresholds enable the port to grow within existing spatial and emission boundaries. Cooperation between the carriers and adaptation of infrastructure use with new ICT systems increases the accessibility and safety. An attractive investment, working and living climate entices leading companies to invest in modern facilities and enthuses young people about jobs in the port. Technical and social innovations increase the adaptive powers of the Port of Rotterdam [53].

Annual report 2010
Port of Rotterdam Authority presents its most important results and aspired future developments to its stakeholders yearly in a report. The results and developments are recapitulated by their strategic altitude. Port of Rotterdam Authority's mission is to develop the leading European port of global structure. Port of Rotterdam Authority formulated a business plan to fulfill its mission, defining the development of the port, safe and efficient handling of shipping as key objectives. Port of Rotterdam Authority sees the development of chains, networks and clusters as the best way to create value for the leading companies in the petro-chemical, energy and transport industry in the port. This vision is realized by an entrepreneurial approach to customers and other ports.

The critical success factors for port development are partnerships with customers and other ports, an efficiently organized port area with good port infrastructure, clean, smooth, safe and secure handling of shipping and a dialogue with the society. A dialogue initiates the support in the society for the development of the port [41]. Moreover realizing the leading European port requires sustainable and innovative approaches [17].

Key performance indicators and targets verify the fulfillment of the critical success factors and projects. They are derived for specific projects in the past and can apply only to a certain extent to the inner lake. Some operational key performance indicators that apply to the inner lake are the market share, throughput, operating expenses, customer satisfaction, sustainability index, turnaround time, modal split and nautical accidents. Organizational key performance indicators, such as commitment of the personnel, sickness absence and performance interviews do not apply to the inner lake [41].

Temporary use inner lake

Port of Rotterdam Authority inventorized and briefly evaluated potential options for the inner lake in several brainstorming sessions and recapitulated the results in an internal document. Activities on the inner lake classified as commercial, innovative or leisure and evaluated by their expected costs and benefits, sustainability, risk, flexibility, image, required organizational effort. Furthermore the document requires that activities comply with the Masterplan of Maasvlakte 2. Activities can only be allocated on the inner lake with temporary contracts and have to be demobilized completely within a short time frame [58].

8.2.2 Deduction of criteria

Classification of criteria

The critical success factor and key performance indicators in the port compass 2030, annual report 2010 and temporary use inner lake document can be classified to the balanced score card's perspectives and translated into evaluation criteria *(see Table 8-1).* The classification to the perspectives can only be done approximately, as the critical success factors and key performance indicators have been retrieved from the port vision in a different way.

The critical success factors of the port compass have probably been derived with a balanced score card-like-method and can be classified straightforward to the four perspectives. Whereas an attractive investment, working and living climate in the port compass provide information for shareholders and customers, the efficient land use of land and infrastructure triggers internal processes, technical and social innovation strive for learning and growth *(see Table 8-1, port compass column).*

Although the annual report contains mainly operational results, it refers at some sections to the port vision with descriptions, critical success factors, and key performance indicators. While, profitability, liquidity, market share, throughput and operating expenses in the annual report are addressed at the shareholders, partner management, customer satisfaction, sustainability and shipping index is dedicated to the customers. Strategic goals, as efficient shipping and organized port areas and key performance indicators as turnaround times, modal split and accidents, are directed to the port's processes. Sustainability and innovation are interpreted as learning and growth objectives *(see Table 8-1, annual report column).*

The evaluation criteria of the temporary use document have not been derived with a balanced score card method. They are classified by the perspectives as good as possible *(see Table 8-1, temporary use inner lake MV2 column).*

Amount of criteria

The classification increases the insight into the meaning of the different critical success factors, key performance indicators and their relation. Several sources adjust each other and give a more complete definition of the perspective [2]. Although more criteria could evaluate alternatives more precise, not all criteria should be fully included into the evaluation. Humans can at most oversee 7 to 9 different aspects at once and more criteria have a higher probability of mutual dependence [62]. Correlated criteria measure the same effects just in another way and could result in similar or contradictionary results. Dependence between criteria cannot be eliminated, only minimized by choosing a balanced set of criteria [71]. Moreover criteria should be objective and measurable [71].

➢ The criteria for the alternatives of the inner lake consist of five main criteria and ten measurement criteria *(see Table 8-1, right column).*

	Sources criteria Port of Rotterdam Authority				Criteria alternatives inner lake
Balanced Score Card Perspective	Port compass	Annual report text	Annual report KPI	Temporary use doc.	
Financial To appear right to our shareholders	-Investment climate	-Profitability -Liquidity	-Market share -Throughput -Operating expenses	-Costs & benefits -Effort for HbR	FINANCIAL -NPV [€] -IC [€] -PI [-]
Customer To appear right to our customers	-Investment, working, living climate	-Entrepreneurial approach -Partnerships -Support in society	-Customer satisfaction -Sustainablity index -Environmental shipping index	-Leisure -Sustainability -Image	SUSTAINABILITY -Hindrance [EIA] -Image [branding]
Process To satisfy our customers and shareholders	-Efficient Landuse -Env. thesholds -Coorp. betw. carriers -Adapt infra use	-Clean, smooth, safe and secure shipping -Efficiently org. port area -Infrastructure	-Turn Around Time -Modal split -Nautical accidents		SYNERGY -Inner lake [coop.] -MV2 [cooperat°] SAFETY -External [dist.] -Nautical [cross.]
Learning To sustain our ability to change and improve	-Technical & social innovation	-Sustainability -Innovation		-Innovation -Flexibility	INNOVATION -Product innovat° [upward pot.] - Process innovat° [upward pot.]

Table 8-1: Deduction of criteria; (left) four perspectives of balanced score card, (middle) grouping of critical success factors and key performance indicators of Port of Rotterdam Authority documents, (right) criteria for evaluation *(see section 8.2.3)*

8.2.3 Definition of criteria

Financial – Financial viability
Money plays a major role in entrepreneurial decisions. The net present value and costs are determined for each alternative *(see Chapter 7 and Table 8-2, financial viability columns)*:

- The net present value represents the sum of the discounted revenues and costs of the alternatives: Alternatives with a positive net present value are profitable. Companies only can ensure their long term existence with profitable projects. This research takes the net present value of the base case, i.e. the service life of the inner lake is 10 years, demolition of the structures and discount rate is 8.5% *(see Section 7.3.1).*
- The net present cost represents the sum of the discounted costs of the alternatives: Alternatives with a large net present costs require larger budgets. Companies have to fund their activities with capital. The required budget is an indicator for the capital costs. This research takes the net present costs of the base case.

Customer – Sustainability
Nowadays people are more aware about the interference between social, economic and ecological issues. Equitable, bearable and viable concepts are often captured by the catchall sustainability *(see Table 8-2, sustainability columns).*

- The hindrance estimates the impact on the port's environment: The Rotterdam Climate Initiative strives for a CO2 reduction of the activities in the port of 50% compared to 1990's emissions level by 2025. The Maasvlakte 2's Environmental Impact Assessment predicts and measures the consequences of port activities from noise, air-, water-, light-, nature-, landscape- to recreational quality.
- The image estimates the branding possibilities: The Rotterdam Climate Initiative and Environmental Impact Assessment are developed in line with environmental regulations, in order to avoid legal actions, retain public support for the ports' development and create an attractive investment, working and living climate [53]. Companies publish information on their sustainable developments by specific media to certain shareholders or even by mass media to the whole society.

Process – Synergy
Companies focus more and more on their core business and create strategic alliances for core related activities. Synergies occur when companies share their resources and usually lead to cost reductions *(see Table 8-2, synergy columns).*

- The Maasvlakte 2 collaboration measures the mutual benefits between the alternatives for the inner lake and the activities on Maasvlakte 2: Port of Rotterdam Authority creates synergies in the port by clustering companies. Clustering reduces operational costs, attracts more companies along the same supply chain and hinders relocation of companies out of the port [36].
- The inner lake collaboration measures the mutual benefits between the alternatives: Collaboration between alternatives is a basically positive. However, too much synergies lead to larger dependencies and larger exposures to economic downtimes. Resilience to economic fluctuations is ensured by a versatile collection of port activities.

Process – Safety
Companies seek in the first place for a cost reduction by decreasing failure costs. Safety regulations not only minimize direct operational cost, but also indirect cost and damage to image *(see Table 8-2, safety columns).*

- The external safety estimates the required safety distances: Port of Rotterdam Authority enlarges the external safety by distances between activities [35]. Safety distances are determined by the probability of fatalities at a certain distance from the incident by risk contours. The inherent safety concerns the failure of components, not of complete systems; it does not have any consequences on its environment.
- The nautical safety estimates the number of vessel crossings with other activities: Port of Rotterdam Authority increases the nautical safety by minimizing the number of encounters, the sailing distances to the quay, clear line of sights, sufficient space for manoeuvres and a Vessel Traffic Service. Small scale activities and gradual upschaling enhances the safety, as existing users can get used to easier to smaller changes [25].

Learning – Innovation
Companies can only ensure their long term existence by competitive advantages. Innovation enables companies to improve existing products, penetrate into other markets, or even create new markets *(see Table 8-2, innovation column).*

- The product innovation measures the upward potential of the structures used: Port of Rotterdam Authority investigates improvements on new products, such as flexible quays, in order to improve the efficiency of the port infrastructure. The prototype phase investigates the feasibility of new concepts practically, indicates the upward potential and is suited for a temporary site like the inner lake.
- The process innovation measures the upward potential of the activity: Port of Rotterdam Authority investigates improvements in processes, such as ICT systems, in order to guarantee future turnaround times.

8.3 Evaluation

Set up
This section evaluates the alternatives with five main criteria in a balanced score card. The evaluation of the financial viability is carried out quantitatively. The evaluation of the other criteria is carried out qualitatively. Alternatives are evaluated relatively to each other. Positive scores are captured with “+” and negative scores with “-“. Alternatives that are indifferent to certain criteria or score neutral are indicated with “0”. These points are not described.

8.3.1 Port activities

Liquid bulk transshipment
- Financial: The net present value is large and net present costs are small.
- Sustainability: Ship-to-ship transshipment at port facilities is less risky than at the North Sea. Port of Rotterdam Authority can brand this safety measure as sustainable.
- Safety: Although additional vessels on the inner lake increase the number of encounters and require safety distances to other activities, they are berthed and supported on the inner lake by port facilities.

Dry bulk transshipment
- Financial: The net present value is relatively small. There are no costs.
- Safety: The expected amount of vessels per year is low. The number of additional encounters is negligible.

Wind turbine assembling facility
- Financial: The net present value is positive in case the contractor quay wall is used. If Port of Rotterdam Authority invests in a quay the net present value is negative.
- Sustainability: Wind turbines produce renewable energy. The transshipment of wind turbines in the Port of Rotterdam contributes to the image of green port.
- Safety: A wind turbine assembling facility increases the number of encounters between sea going vessels and large offshore lifting vessels.

Mooring spaces inland vessels and feeders

- Financial: The net present value is negative. No revenues occur.
- Synergy: Terminals on Maasvlakte 2 and the common barge terminal require mooring spaces for inland vessels as soon as their occupancy rates increases.
- Safety: Mooring spaces ensure that waiting vessels are located at a predefined location out of the port channels. Thus, reducing the probability of collision between a moored vessel and a vessel that sails by.

Common barge terminal

- Financial: The net present value is large, the net present costs as well.
- Synergy: The common barge terminal reduces the demand for mooring spaces. Inland vessels call at fewer terminals. The overall probability of waiting is smaller. Terminal operators can use large equipment on large vessels instead of on small vessels.
- Safety: Inland vessels sail shorter distances in the port. The number of encounters decreases.
- Innovation: The realization of a common barge terminal gives insight in the feasibility of flexible port infrastructures and in the feasibility of the concept of the common barge terminal. The structure can be reused for the common barge terminal in the final phase.

8.3.2 Other activities

Wind energy

- Financial: Regular wind turbines are financial viable for Port of Rotterdam Authority. Energy companies invest from a service life of the inner lake of 10 years.
- Sustainability: Wind turbines cause noise, form an obstacle to birds and deteriorate the landscape. Renewable energy in the port improves the image of a sustainable port.
- Safety: Wind turbines require safety distances for risks of wings break off.

Mussel and algae farming

- Financial: Mussel and algae farming have a very small net present value.
- Sustainability: Floating structures not only enable mussel or algae to grow, but also other species. Fishes and birds find food and shelter.

Hotel at work

- Financial: Hotel at work has a small positive net present value.
- Sustainability: Housing workers at Maasvlakte reduces commuter traffic. Less traffic reduces CO2 emissions. Measures that reduce CO2 can be used as image.
- Synergy: Hotel at work support construction companies at Maasvlakte by offering a place to stay. Construction companies can save time on allocation issues and their employees on travelling time.
- Safety: Distances are required to vessels and port activities.

Fast ferry

- Financial: The fast ferry requires investments and does not generate revenues.
- Sustainability: Usage of public transport reduces usage of private transport.
- Synergy: A stop of the fast ferry is only useful if other activities nearby generate enough passengers. Hotel at work, dolphinarium and terminals might do so.

Nature reserve

- Sustainability: A temporary nature reserve on the inner lake gives species more opportunities to develop. Temporary nature is perceived as rather helping than harming species nowadays.
- Innovation: New regulations make temporary use by nature feasible for developers. The approach can be integrated into the management of port areas and port channels.

Water sports

- Synergy: Water sports are another measure to regulate the nature development. Humans and vessels produce cause hindrance to certain species.
- Safety: Distances are required to vessels and port activities.

Dolphinarium

- Financial: A dolphinarium has a negative net present value.
- Synergy: Visitors of the dolphinarium can make use of the fast ferry.
- Safety: The operator of a dolphinarium wants to attract as many visitors as possible. Port of Rotterdam Authority wants to minimize the amount of visitors for safety reasons.
- Innovation: A dolphinarium requires a quay type structure. The realization of a dolphinarium gives insight into the feasibility of flexible structures.

Balanced Score Card	Criteria									
	Short term		Intermediate term						Long term	
	Financial viability (10 y, 8.5%)		Sustainability		Synergy		Safety		Innovation	
Alternatives for the inner lake	-Net present value [M€]	-Net present costs [M€]	-Consequences [RCI, EIA]	-Image [branding capacity]	-Inner lake [cooperation]	-MV2 [cooperation]	-External [distances]	-Nautical [crossings]	-Product [development phase]	-Process [development phase]
Port activities										
-Liquid bulk	7.5	-0.3	0	+	0	0	-	-	0	0
-Dry bulk	2.0	0.0	0	0	0	0	0	0	0	0
-Wind turbine	2.2	0.0	0	+	0	0	0	-	0	0
-Mooring inland	-0.3	-0.3	0	0	+	+	0	+	0	0
-Mooring feeder	-0.2	-0.3	0	0	+	+	0	+	0	0
-Common barge	8.0	-6.8	0	0	+	+	0	+	+	+
Other activities										
-Wind energy	1.5	0.0	-	+	0	0	-	0	0	0
-Mussel farming	0.1	0.0	+	0	0	0	0	0	0	0
-Algae farming	0.1	0.0	+	0	0	0	0	0	0	0
-Hotel at work	0.4	-0.6	+	+	0	+	-	0	0	0
-Fast ferry	-0.2	-0.2	+	+	+	+	0	0	0	0
-Nature reserve	0.0	0.0	+	+	0	0	0	0	0	+
-Water sports	0.0	0.0	0	0	0	0	-	0	0	0
-Dolphinarium	-0.5	-1.1	0	0	+	0	-	0	+	0

Table 8-2: Evaluation of alternatives for the inner lake on short term (financial viability with service life inner lake 10 years, discount rate 8.5%), intermediate term (sustainability, synergy, safety) and long term (innovation)

8.4 Conclusions

This chapter illustrated the importance of non-monetary value and described four evaluation methods. An overview table method was used to derive evaluation criteria from the port vision, the annual report and an internal document. Alternatives are evaluated on their financial viability (net present value & costs), sustainability (hindrance, image), synergy (collaboration), safety (distances and encounters) and innovation (upward potential).

1) Port activities have in total a net present value of about 20 M€:
   a) Liquid bulk transshipment has a net present value of about 7.5 M€. The inner lake benefit from port facilities and a safer transshipment location than the North Sea.
   b) Dry bulk storage has a net present value of about 2 M€. Transshipment and storage is carried out at the contractor quay wall at a small scale, i.e. hindrance is negligible.
   c) Wind turbine assembling facility has a net present value of about 2.2 M€ in case the contractor quay wall is used. The transport of green cargo with heavy lift vessels is good for the port's image, but requires an extra focus on safety.
   d) Mooring spaces inland vessels and feeders have a negative net present value. They are required in case many vessels have to wait at a quay. More vessels in a port channel increase the chance on collision.
   e) Common barge terminal has a net present value of 8 M€. It creates a win, win, win situation (inland vessels, terminal operators, Port of Rotterdam Authority). Moreover it serves as pilot project for flexible structures. After its service life on the inner lake its structure can be reused, again as common barge terminal, at Maasvlakte 2.

2) Other activities have in total a net present value of about 2 M€:
   a) Wind energy has a net present value of about 1.5 M€. Energy companies invest from a service life of the inner lake of 10 years. Wind turbines cause noise, form an obstacle to birds and require safety distances.
   b) Mussel and algae farming cultivate products for humans, food and shelter for other species. Pilot projects can be carried out at the inner lake and, if successful, applied later on a larger scale elsewhere.
   c) Hotel at work houses workers at Maasvlakte and reduces commuter traffic. Meaning less CO2 emissions and less travel time for construction workers.
   d) Fast ferry can reduce the usage of private transport. Only useful if the activities on the inner lake and Maasvlakte 2 have to generate enough passengers.
   e) Nature reserve gives species the opportunity to develop and is nowadays rather seen as helping than harming flora and fauna. Potential hindrance of protected species on the development of Maasvlakte 2 can be circumvented by regulations.
   f) Water sports can only take place at a certain safety distance from port activities. They can regulate nature development to a certain extent by producing noise.
   g) Dolphinarium has to attract as many visitors as possible to generate revenues. Visitors can travel with the fast ferry. Port of Rotterdam wants limit the amount of people on Maasvlakte 2.

9 Market approach

This chapter describes which alternatives should be brought onto the market and how they should be introduced. Section 9.1 chooses a portfolio matrix and indicates the market attractiveness and competitive strength of each alternative. Section 9.2 analyzes the market and technological risks in matrix and formulates an action plan.

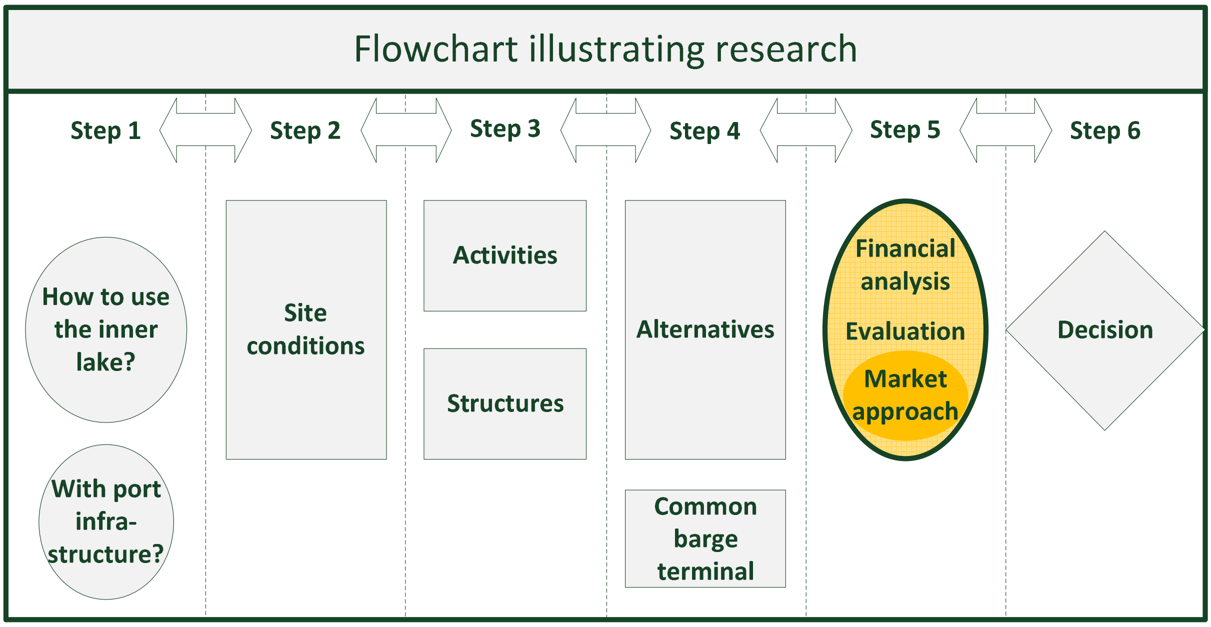


Figure 9-1: Flowchart illustrating research, chapter 9; Indication on which alternatives investment can take place (profitability, competitive strength, market attractiveness) and what risks of implementation are (market, technology)

9.1 Portfolio analysis

Portfolio matrices

Companies can use a portfolio analysis to make strategic choices on their products. A balanced portfolio is required to generate a continuous cash flow. Investing profits from today's activities in growth markets ensures the company's long term existence. The product's profitability and market growth can be indicated in a matrix. The BCG (Boston Consultancy Group) matrix is often used for a portfolio analysis. It indicates the product's lifecycle by its relative market share and market growth in four phases, named respectively: question marks, stars, cash cows and dogs *(see Figure 9-2, left)* [31]:

- Question marks (phase 1): Products are usually launched in a growth market and then have a low market share. Investments into product development, distribution and marketing will eventually decrease total costs and increase revenues.
- Stars (phase 2): Only ingenious products will increase their market share, as many companies enter into growth markets simultaneously. A large market share in a fast growing market together with low costs results in large profits.

- Cash cows (phase 3): Investments on products are less effective as soon as the market growth decreases. Profits from products with a large market share and low market growth should be invested in recently launched products.
- Dogs (phase 4): Relocating investments to products in growth markets result in fewer investments in products in mature markets. Little investments in products eventually decrease the product's market share and induce the end of the product's lifecycle. Products have to be retrieved from the market or relaunched on the market as soon as the profitability is negative.

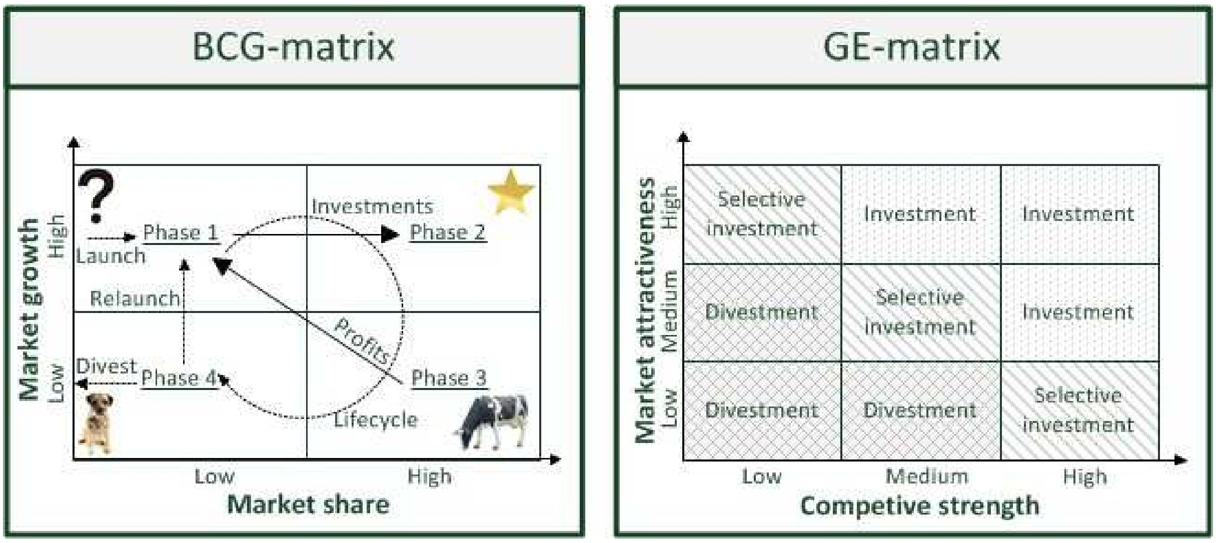


Figure 9-2: Portfolio matrices; (left) the BCG (Boston Consultancy Group) matrix, indicating where to invest in the product's lifecycle with quantitative criteria and (right) the GE (General Electric) matrix, indicating where to invest with qualitative criteria [31]

Although the BCG matrix clearly indicates where investments should take place, the approach is less suitable for this research. The alternatives for the inner lake are still in a conceptual phase and do not correspond to the lifecycle phases of the BCG matrix yet. Moreover the measurement of the relative market share and market growth requires a lot of additional information.

The GE (General Electric) matrix is a generalization of the BCG matrix. It assumes that the optimal business portfolio is not only determined by the market share and market growth, but rather by the company's strength and the possibilities to exploit the most attractive markets *(see Figure 9-2, right)* [31].

The generalization of the axes allows a qualitative definition of the units of measurement adapted to the available data and alternatives. Products are usually classified by a low, medium or high fulfillment of several units of measurements. Multiple units of measurement not only increase the insight into the product's competitive strength and market attractiveness, but also complicate the allocation of the product in the GE matrix. This research uses two unit of measurement per axis;

- Competitive strength: alternatives' required facilities and port relation,
- Market attractiveness: market demand and competition.

Competitive strength – Required facilities

Companies can improve the value of their products by creating and sustaining superior performance at lower costs. Cost reductions enable companies to set lower market prices, or to undertake more investments [3]. Port of Rotterdam Authority dispenses mainly money on salaries and port infrastructure [41]. Lower investments costs of the alternatives on the inner lake reduce directly expenses on port infrastructure and indirectly expenses on overhead, such as salaries. The realization of port infrastructure is managed by Port of Rotterdam Authority and requires organizational efforts.

- Alternatives that require only a few facilities, or can make use of existing facilities on the inner lake make efficiently use of the site conditions and reduce costs.

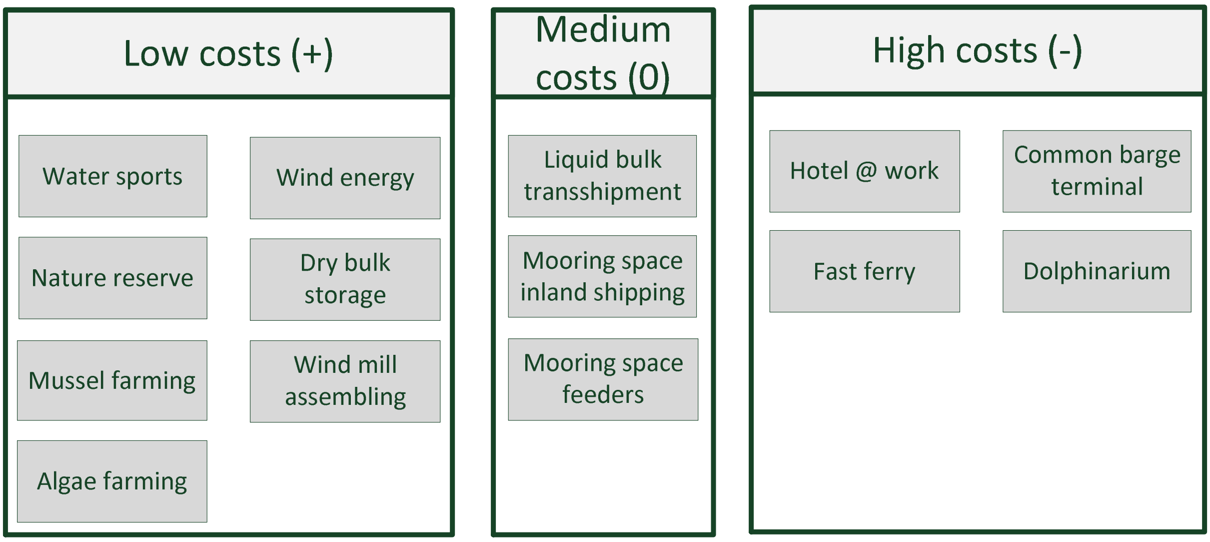


Figure 9-3: Evaluation of alternatives by costs, based on the required facilities

- Low costs (+); Water sports, a nature reserve, mussel farming, algae farming, wind energy, dry bulk storage and wind turbine assembling facility do not require any facilities from Port of Rotterdam Authority. They have a high fulfillment of the costs indicator.
- Medium costs (0); Liquid bulk transshipment, mooring spaces for inland shipping and feeders require mooring facilities. They have a medium fulfillment of the costs indicator.
- High costs (-): Hotel at work, the fast ferry, a dolphinarium and a common barge terminal require a jetty or a quay and have a low fulfillment of the costs indicator.

Competitive strength – Port relation

A higher performance enables companies to set higher prices. Companies produce more successful products and deliver better services, when they focus on their core competencies. The core competencies of a company concern the coordination of skills and the integration of multiple technologies into a product [3][31]. Port of Rotterdam Authority coordinates the nautical traffic, allocation of companies and realization of infrastructure in the port. Furthermore it integrates port infrastructure and traffic optimization systems into an efficient supply chain [41]. Although the Port of Rotterdam serves many industries, it is mainly used by and adapted to port bound market segments, such as liquid bulk, dry bulk and containers. Activities in similar segments can be integrated easily into the Port of Rotterdam, as Port of Rotterdam Authority can make use of its existing resources and skills.

Most companies that integrate activities into their portfolio that do not relate to their core competences tend to abandon these activities again [3].

➢ Port activities fit better to Port of Rotterdam Authority's core competencies than other activities.

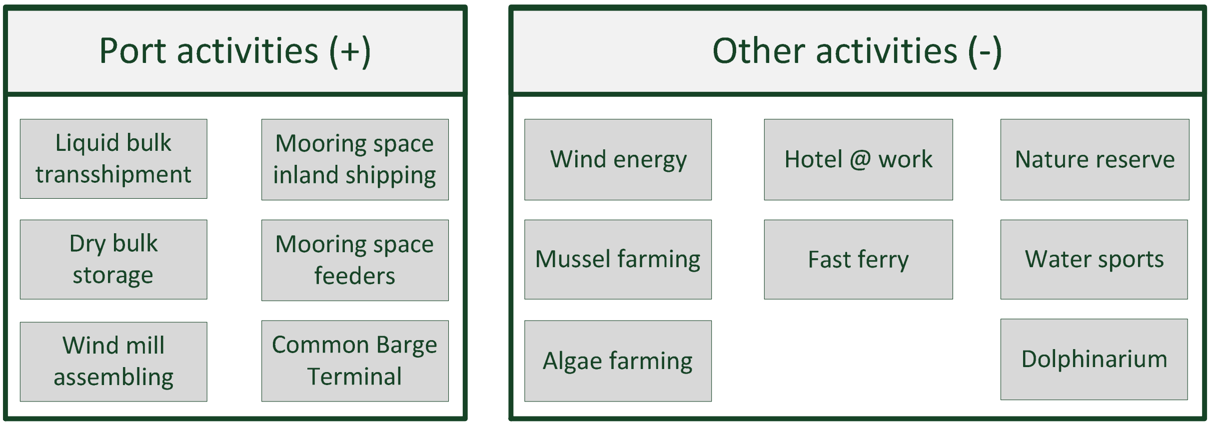


Figure 9-4: Evaluation of alternatives by relation to Port of Rotterdam authority

- Port alternatives (+): Liquid bulk transshipment, dry bulk storage, wind turbine assembling facility, a common barge terminal, mooring spaces for inland shipping and feeders are port bound activities and have a high fulfillment of the core competencies indicator.
- Other alternatives (-): Wind energy, mussel farming, algae farming, hotel at work, the fast ferry, a nature reserve, water sports and a dolphinarium are not directly related to the Port of Rotterdam and have a low fulfillment of the core competencies indicator. However, the interest of Port of Rotterdam Authority in energy related activities can ease the integration of wind energy and algae farming [53].

Market attractiveness – Demand & Competition
The value of products in the market is determined by the demand and competition. Products can generate more revenues in a larger market with less competition [3].

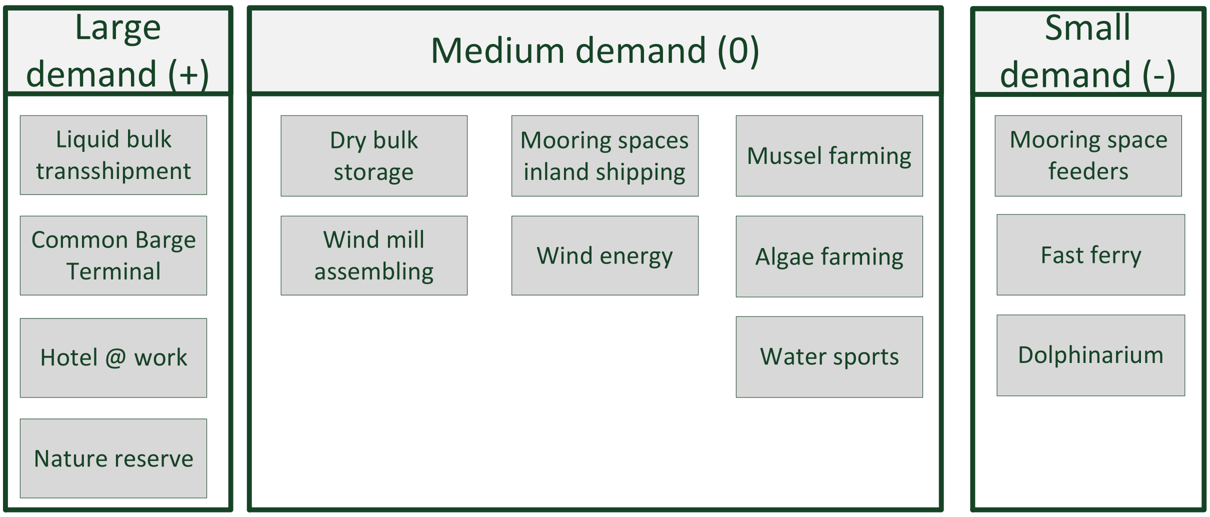


Figure 9-5: Evaluation of alternatives by expected demand

➢ The demand can be determined with the customer base of the activity or comparable activities.

- Large demand (+): The market for liquid bulk transshipment, common barge terminal, hotel at work is large and a nature reserve.
  - The market for ship to ship transshipment is large in the North Sea. The first mooring facilities in the Calandkanaal had a payback time of about one year [49].
  - The expected increase in container transport for the upcoming decades will lead to several terminal expansions on Maasvlakte 2 [35].
  - About 2,000 temporary workers are expected on Maasvlakte *(see Figure 3-11).*
  - Nature associations always strive for more nature reserves.
- Medium demand (0): The market for dry bulk storage, wind turbine assembling, mooring spaces for inland shipping, wind energy, mussel farming, algae farming and water sports are neither large nor small.
  - If governments hold their renewable energy targets, the demand for wind turbine assembling facilities rises considerably [66].
  - The fast ferry can become more important if Port of Rotterdam Authority and its customers decide together to reduce commuter traffic on the A15 motorway [56].
  - The demand for mooring facilities for inland shipping increases as soon as the terminal occupancy rate reaches its maximum *(see Section 6.2).*
- Small demand (-): The market for mooring spaces for feeders, the fast ferry and a dolphinarium is small.
  - Feeders have at high quay occupancy rates priority over inland vessels [55].
  - Activities at the inner lake and Maasvlakte 2 do not attract many people. The potential demand a stop of the fast ferry on the inner lake is small.
  - The number of visitors of the dolphinarium in Harderwijk and Ecomare has decreased over the past years [12].

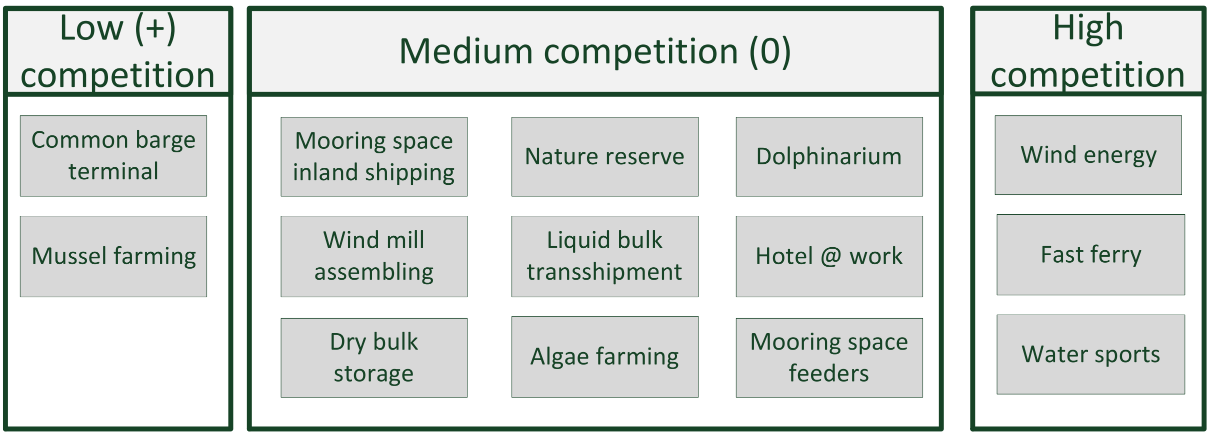


Figure 9-6: Evaluation of criteria by expected competition

➢ The competition can be determined with the strength and weaknesses of current and potential rivals. Some activities can take place at several locations. Others have to take place in the Port of Rotterdam. Their rivals are other locations in the port.

- Low competition (+): The competition for the common barge terminal and mussel farming is low.
  - The common barge terminal can be strategically located between the terminals on the inner lake. Dedicated inland shipping quays on Maasvlakte 1 are already occupied by other terminals and too far away [55].
  - Mussel farmers will lose their permission to gather seeds on natural banks. They did not developed efficient techniques yet to gather seeds in a harsh environment [50].
- Medium competition (0): The competition for liquid bulk transshipment, dry bulk transshipment, mooring spaces for inland & feeders, wind turbine assembling, hotel at work, dolphinarium, nature reserve and algae farming is neither large nor small.
- High competition (-): The competition for wind energy, water sports and the fast ferry is high.
  - The expected availability at the inner lake is lower than at other sites and the average payback period of wind farms [35].
  - Water sports can make use of the beach at the sea defense, or of other dedicated locations all over Netherlands.
  - The fast ferry is hardly used by commuters. Most companies in the port are better connected to private than public transport [56].

Portfolio matrix
The alternatives for the inner lake are allocated in the GE matrix by their competitive strengths, market possibilities and profitability ratio *(see Figure 9-7).* The profitability ratio represents the net present value over the net present costs. It enables investors to select the most profitable projects, in case funds are limited [62]. A positive profitability ratio indicates that the net present value is larger than the net present costs (positive number, green). A negative profitability ratio indicates that the net present value is smaller than the net present costs (negative number, red). In some cases no costs occur ("NA"), or costs and revenues occur (grey, "0"). Expected future developments on competitive strength and market attractiveness are indicated with arrows.

The allocation of the alternatives on the GE matrix indicates how to proceed *(see Figure 9-7)*:

- Alternatives in the top right box of the GE matrix match well with Port of Rotterdam Authority's core competencies and the site conditions of the inner lake. Moreover they can be introduced onto a market with a considerable size without too much competition. Port of Rotterdam Authority can initiate liquid bulk transshipment on the inner lake.
- Alternatives in the top right diagonal are less attractive. Port of Rotterdam Authority has to investigate a dry bulk storage facility, wind turbine assembling, mooring spaces for inland shipping, common barge terminal, mussel farming and nature reserve.
- Alternatives on the main diagonal have a reasonable match with Port of Rotterdam Authority's competitive strengths and the market. They are not suitable for an implementation at the first place, but can be kept on shelf and realized in case market conditions change. Port of Rotterdam Authority should not take the initiative with mooring spaces for feeders, wind energy, algae farming and hotel at work.
- Alternatives in three bottom left boxes are not suitable for temporary use on the inner lake. Port of Rotterdam Authority can ignore a fast ferry, water sports and dolphinarium on the inner lake.

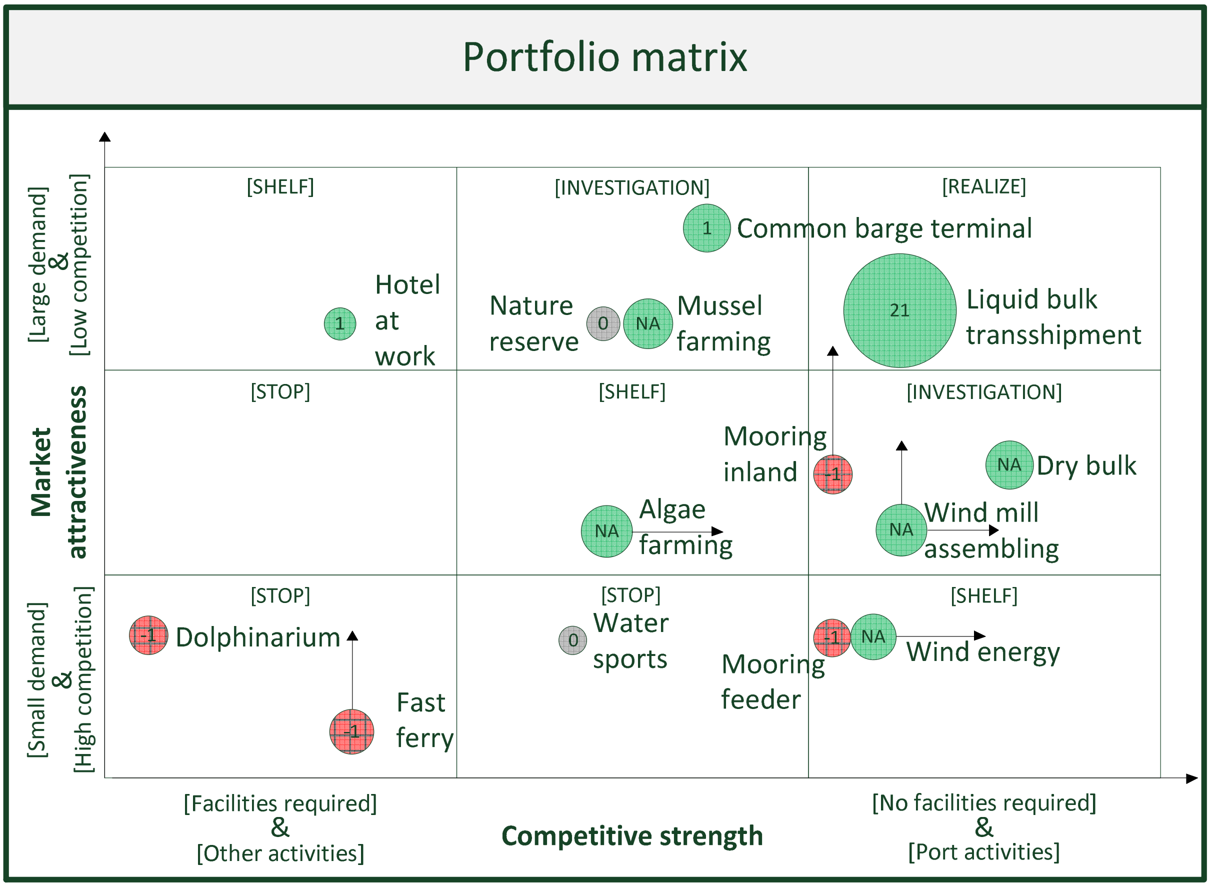


Figure 9-7: Portfolio matrix with competitive strength (horizontal axis), vertical strength (vertical axis) and profitability ratio (numbers), boxes; top right = realize, top right diagonal = further investigation, main diagonal = leave on shelf, bottom right = stop

9.2 Action plan

Risks of implementation

After the GE matrix specified on which alternatives investments are effective, this section indicates how the alternatives can be brought onto the market. The implementation of the alternatives is subjected to several risks. Launching a product with a new technology into a new market is more challenging than launching a product with existing technologies into an existing market [3]. Companies can make use of their operational experience when they implement common products into markets that are familiar to them. New technologies require special attention to the connections with existing technologies and have to overcome the market resistance against the modification of existing solutions. Products that penetrate into a new market have to find a business unit within the company and have to be implemented with an appropriate business model [3].

➢ New technologies and markets form a higher risk to a successful implementation of alternatives for the inner lake than common technologies and familiar markets.

Technological risks

- The common barge terminal and dolphinarium have to be constructed with a quay. The site conditions of the inner lake pose unusual requirements to the structures. Port of Rotterdam Authority requires a clear site after the usage of the temporary inner lake and a demobilization of all structural components [55]. Up to now, most structures have been designed for usage, neither for demobilization nor for reuse. Dismountable structures require special joints and points of attachment for lifting equipment. Joints and attachment points pose a larger risk of technical failure.
- Wind farms do not pose large technical risks themselves, but their connection with the grid can do so. Cables intersect other infrastructure bundles and interests of shareholders. Specific requirements of shareholders can lead to complex technical solutions.
- Hotel at work, the fast ferry, liquid bulk transshipment and mooring facilities for feeders and inland vessels are constructed with jetties and mooring structures. Pile type structures can be demobilized and reused quite easily. Jetties are sometimes relocated from silted-up areas to deeper water.
- Dry bulk storage and wind turbine assembling can make use of the contractor quay wall and require at most some small adaptations. Mussel farming, algae farming, water sports and a nature reserve do not require any structures from Port of Rotterdam Authority.

Market risks

- The dolphinarium, algae farming and mussel farming are new markets for Port of Rotterdam Authority. A dolphinarium requires collaboration with another dolphinarium, e.g. Harderwijk, and some knowledge of the leisure market. Experience with large events, such as the world port days, is beneficial [55]. Port of Rotterdam Authority has some experience with leisure and professional fishing regulations, but not yet with commercial aqua farming [50].
- The spatial planning of water sports, a nature reserve, wind turbines, the fast ferry and hotel at work has been done for Maasvlakte 1. It is integrated into several project departments of Port of Rotterdam Authority.

- STS liquid bulk transsshipment and wind turbine assembling are still quite new activities at the Port of Rotterdam. However, they can be integrated into existing business units.
- Dry bulk storage and mooring spaces for feeders and inland vessel concern Port of Rotterdam Authority's day-to-day business and can be easily managed at their corresponding departments.
- The concept of a common barge terminal is rather new. The market success of the common barge terminal depends on the willingness of the terminal operators to participate. Mutual use of the common barge terminal requires a close collaboration between the terminal operators and Port of Rotterdam Authority. Terminal operators are reserved about participation models. The container market is highly competitive. They rather prefer to maximize their own profits over the profits of all terminal operators on Maasvlakte 2.

Risk matrix
The technological and market risks of each alternative are captured in a risk matrix *(see Figure 9-8).* The relative importance of the risks is indicated by the net present costs. Large net present costs that are exposed to large risks should generate more profits and require mitigating measures [3]. The size of the spheres indicates the estimated net present costs of Port of Rotterdam Authority (blue), of its customers (yellow) and of both parties (green).

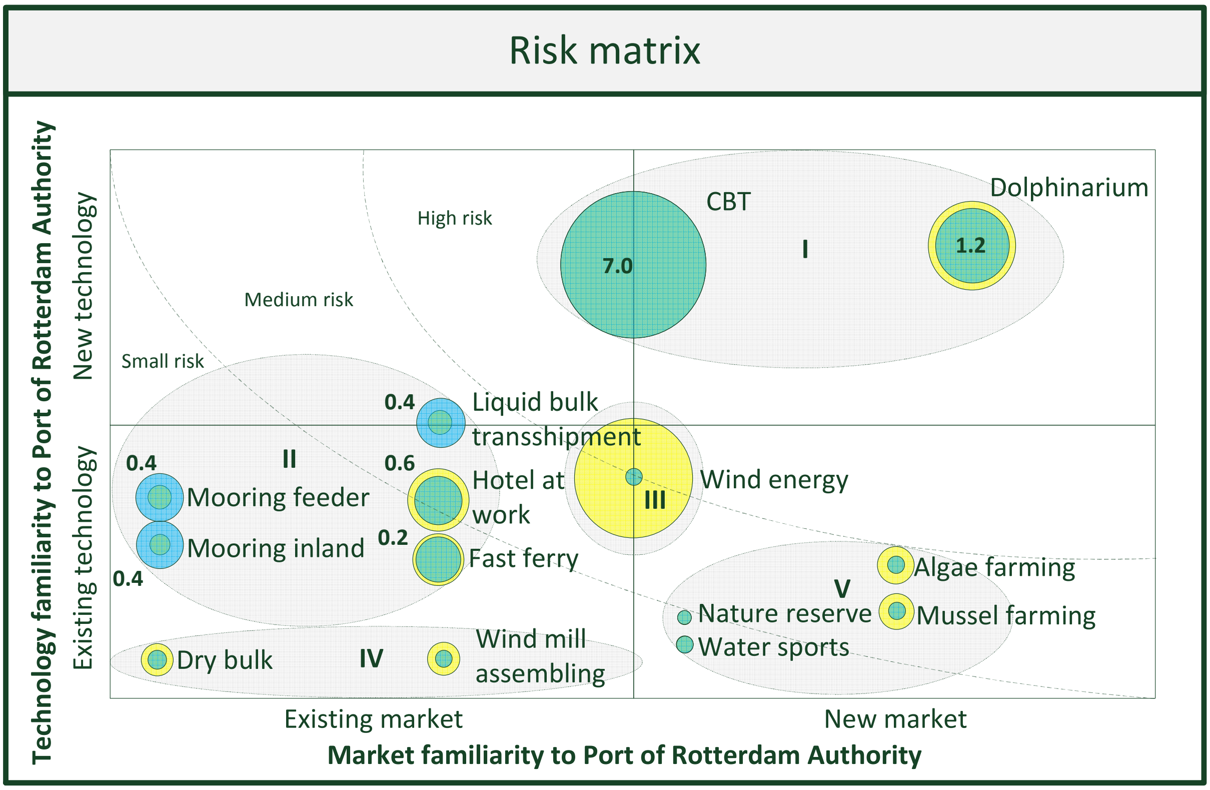


Figure 9-8: Market (horizontal axis) and technological (vertical axis) risk per alternative; net present costs for Port of Rotterdam (numbers in M€, blue), customer (estimated, yellow) and minimum net present costs per party (green)

Risk sharing
Port of Rotterdam Authority and its customers can take both mitigating measures. The relative importance of the risks to Port of Rotterdam Authority and its customers is indicated by the net present costs *(see Figure 9-8).* Port of Rotterdam Authority has to bear most risks in case its net present costs are larger than the net present costs of its customers. The other way around the customers should bear most risks in case their costs are larger than Port of Rotterdam Authority's costs. Risks have to be shared in case net present costs are more or less equal. The individual contribution has to be negotiated and depends, besides the risks, on interests of each party in the alternatives.

Contracting
The alternatives have different structural requirements. Some alternatives require a dedicated structure; other can make use of the existing facilities. Alternatives that can be realized with similar contracts are grouped by Roman numerals *(see Figure 9-8).*

i) Quays for the common barge terminal and a dolphinarium comprise demobilization and potential reuse as main requirement. Contractors have specific know how, equipment and preferred suppliers. They can come up with clever solutions for the assembling of the structural component and determine the most suitable structure for the inner lake. Alliances can be used to mitigate risks.
ii) Jetties and mooring structures for inland shipping, feeders, liquid bulk transshipment, the fast ferry and hotel at work have been demobilized and reused before. Contractors have experience in assembling and demobilizing jetties and mooring structures. A specification can be used.
iii) An energy company is responsible for the construction and demobilization of wind turbines. The requirements to the intersections with infrastructure bundles should be formulated by Port of Rotterdam Authority in a specification.

The alternatives for the inner lake are usually applied at locations that are longer available than the inner lake without short cancellation periods. Port of Rotterdam Authority can compensate for the short availability of the inner lake in several ways. It could help to apply for subsidies and guarantee relocation options within the port after service life ends on the inner lake. Compensations are required for alternatives with long payback periods, i.e. large net present costs *(see Figure 9-8)*:

- Energy companies for example usually presume a payback period of 10 years or more [67].
- Contractors that assemble wind turbine for example only require a quay for several months [59].

All customers have to be clearly informed about the expected service life of the inner lake and the cancellation periods. The implementation of the alternatives can commence after the first phase of Maasvlakte 2 has been completed in 2014. The duration of the contracts can be adjusted to the expected throughput on Maasvlakte 2 and should decrease from 2014.

9.3 Conclusions

This chapter described how to proceed with the alternatives for the inner lake. The portfolio matrix indicated with competitive strength, market attractiveness and profitability ratio whether Port of Rotterdam Authority could start to realize, further investigate, wait or stop with the alternatives. The risk matrix indicated with the technological risk, market risk and net present costs what type of contract can be used.

1) The portfolio matrix indicates that Port of Rotterdam Authority could:
   a) Realize liquid bulk transshipment on the inner lake.
   b) Further investigate the technological and market risks of a dry bulk storage facility, wind turbine assembling, mooring spaces for inland shipping, common barge terminal, mussel farming and nature reserve on the inner lake.
   c) Wait market initiatives with mooring spaces for feeders, wind energy, algae farming and hotel at work on the inner lake.
   d) Stop thinking about a fast ferry, water sports and dolphinarium on the inner lake.

2) The risk matrix indicates that Port of Rotterdam Authority could:
   a) Form alliances with the contractor and operator in order to mitigate risks of the realization of a common barge terminal and dolphinarium on the inner lake.
   b) Use specifications to realize mooring structures and jetties for liquid bulk transshipment, mooring spaces for inland vessels & feeders, hotel at work, fast ferry and wind turbines on the inner lake.
   c) Compensate customers of alternatives with large net present costs in port charges or relocation costs, i.e. common barge terminal, wind energy, dolphinarium.
   d) Charge customers of alternatives with low net present costs with market-orientated prices, i.e. the other alternatives.
   e) Clearly inform customers about the expected service life (per parcel), cancellation periods and relocation possibilities within the Port of Rotterdam.

10 Conclusions & recommendations

This research examined the possibility of allocating temporary activities to the temporary inner lake of Maasvlakte 2, using flexible port infrastructures. Section 10.1 summarizes the main conclusions of this research. Section 10.2 gives recommendations on the use of the temporary inner lake and the implementation of flexibility in port infrastructure.

10.1 Conclusions

How to make use of the temporary inner lake?
The best activities are chosen with a portfolio matrix and balanced score card. Port activities, other activities or a combination of both are feasible on the inner lake.

1) Financial top 3 (largest net present value – port activities):
   a) Liquid bulk transshipment has a net present value of about 8 M€. The inner lake benefits from the presence of port facilities and provides a safer transshipment location than the North Sea.
   b) Common barge terminal has a net present value of 7.5 M€. It creates a win, win, win situation (inland vessels operators, container terminal operators and Port of Rotterdam Authority). Moreover it serves as pilot project for flexible structures. Structures can be reused for the after their service life on the lake.
   c) Wind turbine assembling facility has a net present value of about 2.2 M€ in case the existing contractor quay wall is used.

2) Non-monetary top 2 (net non-monetary value – other than port activities):
   a) Floating mussel cultures serve as pilot for mussel farmers and shelter for species.
   b) Nature reserve gives species the opportunity to develop. New regulations permit temporary nature space and allow developers to proceed with their projects if required.

How to make use of the temporary inner lake with flexible port infrastructure?
A common barge terminal is the only alternative that requires a quay type structure. Its net present value has been calculated with several structures:

3) Structures with the largest net present value have the lowest whole lifecycle costs:
   a) Large prefabricated structures, i.e. barge, caisson, very large floating structure and L wall, have larger whole lifecycle costs than (semi) modular structures, i.e. Maxisteck, sheet pile wall and Containerland.
   b) Structures with single use components, i.e. Containerland, have smaller whole lifecycle costs than multiple use structures, i.e. all other structures.

4) Reuse-possibilities have to be considered in case the rest value after the first service life in the inner lake is large:
   a) The probability of reuse depends on the match of the site conditions in the port (soil, slope), with customer requirements (retaining height, bearing capacity, service life over remaining lifetime structure) and market (number of infrastructure projects).
   b) The rest value of Containerland is considerably in case the service life is shorter than 10 years and the discount rate smaller than 8.5%.

10.2 Recommendations

How to proceed with the temporary inner lake?
The portfolio matrix and balanced score card indicated the top 5 activities for the inner lake.

1) Port of Rotterdam Authority could:
   a) Realize one liquid bulk transshipment facility on the inner lake.
   b) Estimate the profits and losses of the container terminal operators through use of the common barge terminal.
   c) Estimate the number of offshore wind farm projects and available assembling facilities around the North Sea in order to determine attractiveness of the inner lake.
   d) Investigate with a pilot project whether mussels grow (fast enough) at the inner lake.
   e) Discuss the potential advantages of a temporary nature reserve and the regulations required to enable this through dialogues with other project developers, e.g. ports and municipalities.

How to implement (more) flexibility in port infrastructure?
This research determined with the help of scenarios and several parameters based on expert opinions the whole lifecycle costs of several structures for a single activity. The structures' whole lifecycle costs depend on the site conditions, market conditions and design approach.

2) Port of Rotterdam Authority could create a portfolio of best structures and:
   a) Verify the prices of coated second hand containers, lifetime containers and replacement costs.
   b) Determine whole lifecycle costs of several structures;
      - with components with different lifetimes (steel, concrete,…) and modularities,
      - with different scenarios and input parameters (discount rate & service lives),
      - for several retaining heights (quays) and slopes (jetties).
   c) Make an inventory of the slopes and structures in the Port of Rotterdam.
   d) Compare whole lifecycle costs of structures with those in the Port of Rotterdam and hinterland. Choose most suitable structure per retaining height and slope. Set standards in the market by realizing only best structures.

3) Port of Rotterdam could develop an design approach that incorporates flexibility and:
   a) Evaluate projects with lower discount rate;
      - new technologies can only be successful implemented with less profits,
      - scenarios should incorporate risks, i.e. upward potential of flexible structure <u>and</u> downward losses of robust structures.
   b) Monitor port infrastructure prices and number of projects in Port of Rotterdam and its hinterland in order to determine:
      - what the best practice after the structure's service life (reuse, sell, demolition) is,
      - when the structure has to be demobilized, e.g. a demobilization before the service ends can increase the probability of reuse.

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Appendices

A Activities

A.1 Results brainstorming session

Figure A-1: Overview of activities grouped by segment and ranked by overall feasibility in the brainstorming session on 4 April 2011, World Port Center, Rotterdam

A.2 Additional activities

This section describes the activities that were not ranked among the most feasible 14 activities *(see Section 3.2)*, but investigated in this research.

A.2.1 Port activities

Sand & gravel storage
The inner lake could be used to store construction materials. The concessions along the Dutch rivers elapse in some years. More sand is extracted from the North Sea. More gravel and stones are imported from Norway. These materials could be stored in the inner lake [43]. However, speculative storage, as with liquid bulk, is not beneficial, because indexed sand and gravel prices rather decrease than increase [19]. Wholesale trade, i.e. buy large amounts for a low price, sell small amounts for a high price, is not beneficial either. The North Sea is almost as close to the consumer market as the inner lake and handling costs are smaller.

Also the storage of coarser construction materials in the inner lake, such as riprap, is probably not financially viable. Coarser materials are usually stored on above the water surface and transported in large amounts [43]. Above water storage requires horizontal transshipment and large transport amounts require larger vessels and with larger drafts. Even for self-unloaders with long discharge booms cannot unload at a natural slope and require port infrastructure. Port infrastructure for larger drafts is already available elsewhere in the Port of Rotterdam [43].

Nautical services
There is no need at present to accommodate nautical services, such as tugs, on the inner lake. Nautical services will be allocated in the service harbor on Maasvlakte 2 [55].

Offshore equipment
There is no need for a mooring space for offshore equipment, such as pipe laying vessels, at present. The offshore facilities in the Calandkanaal had a low occupancy so far [49].

Dock
The closed part of the inner lake can be used as a site for constructing or demolishing large structures. Tunnels are planned under the Nieuwe Waterweg [51]. Elements of the Blankenburgtunnel and Oranjetunnel can be constructed in the closed part of the inner lake. Many offshore platforms in the North Sea have to be dismantled in the years to come [49]. Stricter regulations might prohibit dismantling under primitive conditions in South Asia. Offshore platforms and vessels can be dismantled on the inner lake.

A.2.2 Other activities

Floating wind turbines
Floating wind turbines are mounted on floating structures and can be easily relocated to other sites. Some floating wind turbines can be relocated with chains in the wind farm to minimize the wake effect, i.e. avoid that wind turbines are positioned in front of each other. Floating wind turbines have lower investment costs than bottom fixed wind turbines from about 40 m water depth. In the southern North Sea water depths are smaller than 40 m [21].

Small scale wind turbines
Small scale wind turbines are mounted on buildings to produce additional energy. This is so small that most small scale wind turbines are not beneficial. Moreover only a few permits are given out, due to safety reasons and noise [27].

Solar energy
Solar energy converts sunlight, via photovoltaics, into electrical energy. The power density per year of solar energy amounts about 1000 kWh/m2 in the Netherlands and is about the same as for wind energy. However, the power density produced varies over the year. In winter times, when the demand for energy is higher, the power density for wind energy is higher and for solar energy lower. Moreover the power density also varies over the surface. Whereas for the same power density wind turbines are, for efficiency and safety reasons, located at intervals of about 250 m, solar panels have to be located next to each other [11].

Furthermore solar panels are mostly attached to buildings, to decrease investment cost. Because there are no buildings at the inner lake yet, solar energy will be more expensive than usual. Nowadays, electrical energy from solar energy is already several times more expensive than from wind energy [8].

Floating solar panels might be able to produce electricity at lower costs in the future. Solaris Synergy and EDF launched floating panels in September 2011 that are able to convert more sunlight into electricity through use of mirrors and a water cooling system. Moreover they have a lower environmental impact than conventional floating solar panels, since oxygen can penetrate through the panels into the water [15].

Hydro power
Hydro power converts kinetic energy into electrical energy and can be more efficient than wind energy. Water is more than 800 times denser than air. Hydro power could be generated on the inner lake from the horizontal and vertical tidal movement.

Horizontal tidal movement can be converted into hydro power with tidal stream generators. Tidal stream generators are basically wind turbines under water and require a flow velocity of several m/s [29]. The flow velocity in the inner lake, and even in the Yantzehaven, is lower than 1 m/s [10].

Vertical tidal movement can be converted into hydro power with tidal barrages. The potential energy head between high and low tides in a ponding area is converted into electricity. However, a minimum throughput per turbine and net head difference is required. The maximum tidal range in the Maasvlakte is 1.7 m [48].

This range decreases as soon as a barrage is built. Even a one-directional very low head turbine still requires a head larger that is larger than 1.4 m [23]. Thus, hydro power is not attractive at the temporary inner lake.

Energy storage

Energy storage by water buffer can adapt the energy production to the demand. Wind turbines produce electricity if the wind blows. Energy storage by water buffer, such as plan Lievense, is not financially viable [14]. High dikes and large stilling basins have to be constructed.

Thermal power

Thermal energy converts heat energy via heat exchangers into electricity. The power plant at Maasvlakte 1 discharges its cooling water into the Arianehaven. The cooling water is warmer than the water in the Arianehaven. If the temperature difference between the cooling water and surrounding water is large enough to generate electricity, the power plant will work. Since thermal power plants have long payback periods, they do not seem financially viable on the inner lake.

Agriculture

Agriculture can be allocated on the water by floating glass houses. New patented concepts can decrease the construction cost considerably [5].

Cumbersome engineering processes and vacant glasshouses in the Westland form a bottleneck for these new concepts [4].

Fish farming

Another kind of aquaculture is fish farming with cage, pond, or recycling systems. Cage systems are flexible, can be replaced easily, but usually also have the highest rates of escape. Escaping fishes can carry over diseases. Recycling systems are sophisticated, can adjust water temperature, quality and are covered with a hall [24]. Cost reductions by using the cooling water from the nearby power plant were not enforceable and led to the bankruptcy for the Happy Shrimp farm [57]. Pond systems are often constructed with fabric that prevents the average water level from declining. The inner lake has a fixed average water level and a dike that could be used to create a pond [24].

However, the Dutch fish farming industry has failed over the past years to set up a competitive business. Expensive systems, high labor and logistic cost have increased the production costs of fresh Dutch fish. Customers choose more often for frozen or refreshed imported fish. Recent discovered on-demand feeding systems still have to be implemented and will only decrease production costs in the long run [24].

A.3 Revenues

This section describes the input parameters for calculating revenues from port and other activities *(see Section 7.2.2).* These revenues are in the form of port dues, rent and mooring dues. A short description of the activities and the assumptions follows.

A.3.1 Port activities

Liquid bulk transshipment
Liquid bulk transshipment can take place with Suezmax vessels at the current site conditions of the inner lake. They have a DWT of 150,000, a LOA of about 200 m, a draft of 14.5 m [30]. For larger vessels the inner lake has to be deepened locally. Very Large Crude Carriers with a draft larger than 20 m are not feasible. For these vessels the Yantzehaven has to be deepened.

The number of transshipments is estimated with market information. In the North Sea about 264 transshipments took place in 2010 [49]. Most of them were carried out at Southwold (UK) and at Skagen (DK). These areas are free of port dues. Yearly about 20 transshipments take place at Skapa Flow (UK) that charges similar port tariffs as the Port of Rotterdam [39].

Conservative numbers are taken for number of transshipments and occupancy rate: every two weeks a transshipment of 40,000 DWT takes place (26 per year) and 20% of time a vessel berths at the liquid bulk transshipment facility for temporary storage.

Dry bulk storage
An importer of granite blocks wants to its cargo at the contractor quay on Maasvlakte 2. It is assumed that the importer's smallest vessel, the SMT Bontrup, will call about 4 times per year and transships 90% of its cargo, i.e. 40,000 t [30].

Wind turbine assembling
Wind turbine assembling could take place at the contractor quay if the lifting equipment requires less than 50 m quay length. An average offshore wind farm consists of 32 2-MW wind turbines with a total weight of about 150 t [6]. It is assumed that 3 average sized wind farm projects are carried out per year and that they require a site of 75,000 m^2 [59].

Inland vessels
Inland vessels make use of mooring facilities as soon as the quay occupancy increases. Mooring facilities for inland vessels are seen as a necessity to improve the safety and accessibility in the port. The income from mooring dues does not apply to one particular facility [55].

Feeders
Feeders are seagoing vessels with an average LOA of about 150 m and have to pay mooring dues [30]. They have a higher priority at the terminals than inland vessels. It is assumed that the occupancy rate over the service life varies around 20%.

Common barge terminal
The common barge terminal requires a site of about 80,000 m^2 and a quay length of 300 m. The net present cost savings due to a common barge terminal vary per year is elaborated upon other sections *(see Chapter 6.3 and Appendix C).*

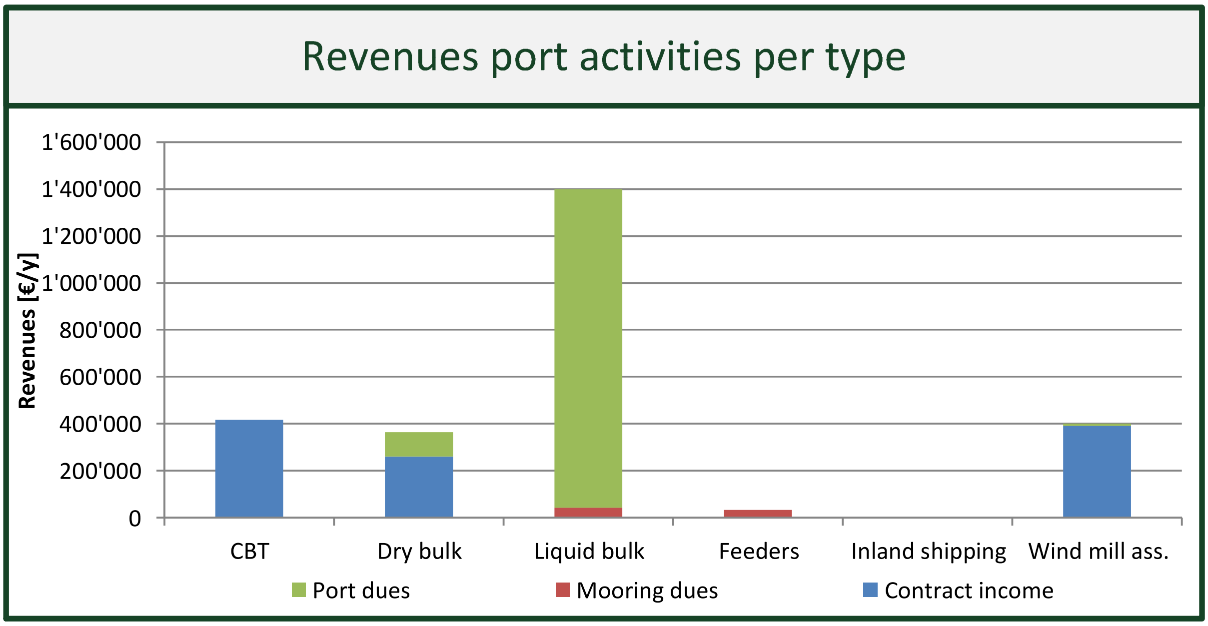


Figure A-2: Port dues (green column), mooring dues (red column) and rent (blue column) of the port activities per year

A.3.2 Other activities

Wind energy

The wind turbine concession tariffs of the Dutch government are 12,500 €/MW/y [44]. It is assumed that 10 2-MW wind turbines are constructed on the inner lake. Wind turbines are financed and operated by private parties. The investment costs for 55 5-MW wind turbines 30 km off the Belgium coast are 4.7 M€/MW. The payback period is about 12 years in case there are 3,300 operational hours per year (37% of the year), an operator receives 50 €/MWh for its produced electricity and 107 €/MWh through green energy certificates [6].

Mussel farming & algae farming

Mussel and algae farming are often carried out at public areas and charged by lease fees. About 1 kg/m^2 mussel and algae can be produced at the inner lake [50]. It is assumed that the retail price amount to 5 €/kg and that 5% of the retail price is charged as lease fee. Furthermore it is assumed that an area of 100,000 m^2 is rented.

Hotel at work

A floatel at the inner lake is berthed at a jetty. It is assumed that floatel with an average LOA 200 m and a berth occupancy rate of 80% over the service life is used.

Fast ferry

It is assumed that the fast ferry does not generate revenues for Port of Rotterdam Authority.

Nature reserve

It is assumed that the fast ferry does not generate revenues for Port of Rotterdam Authority.

Water sports

It is assumed that the fast ferry does not generate revenues for Port of Rotterdam Authority.

Dolphinarium

A dolphinarium on the inner lake would be an affiliate of the dolphinarium in Harderwijk (NL). It is assumed that its size is in the same order of magnitude as the sea mammal zoo Ecomare in De Koog (NL). The number of visitors of the dolphinarium and Ecomare decreased over the past years to respectively 800,000 /y and 300,000 /y. Ecomare has a parcel of about 20,000 m^2. It generates mainly revenues from entrance fees (2.4 M€/y) and subsidies (1.6 M€/y) [12].

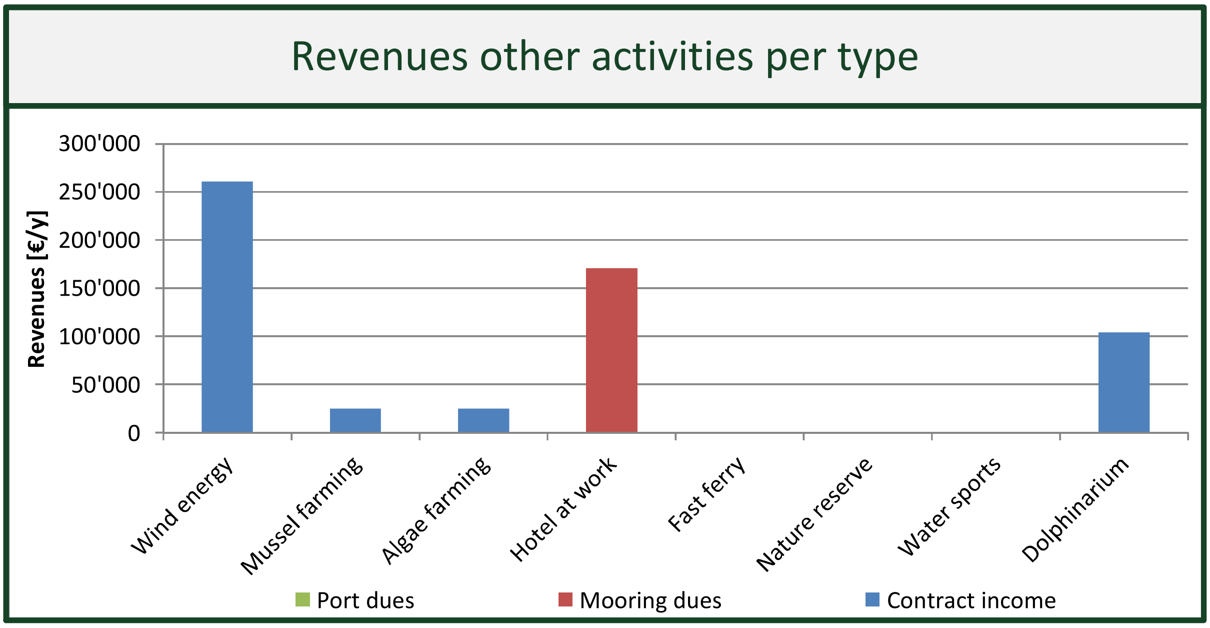


Figure A-3: Port dues (green column), mooring dues (red column) and rent (blue column) of the other activities per year

A.4 Net present values

This section presents the effect of the variation of the discount rate and the service life in the inner lake on the net present value of each alternative *(see Section 7.3).*

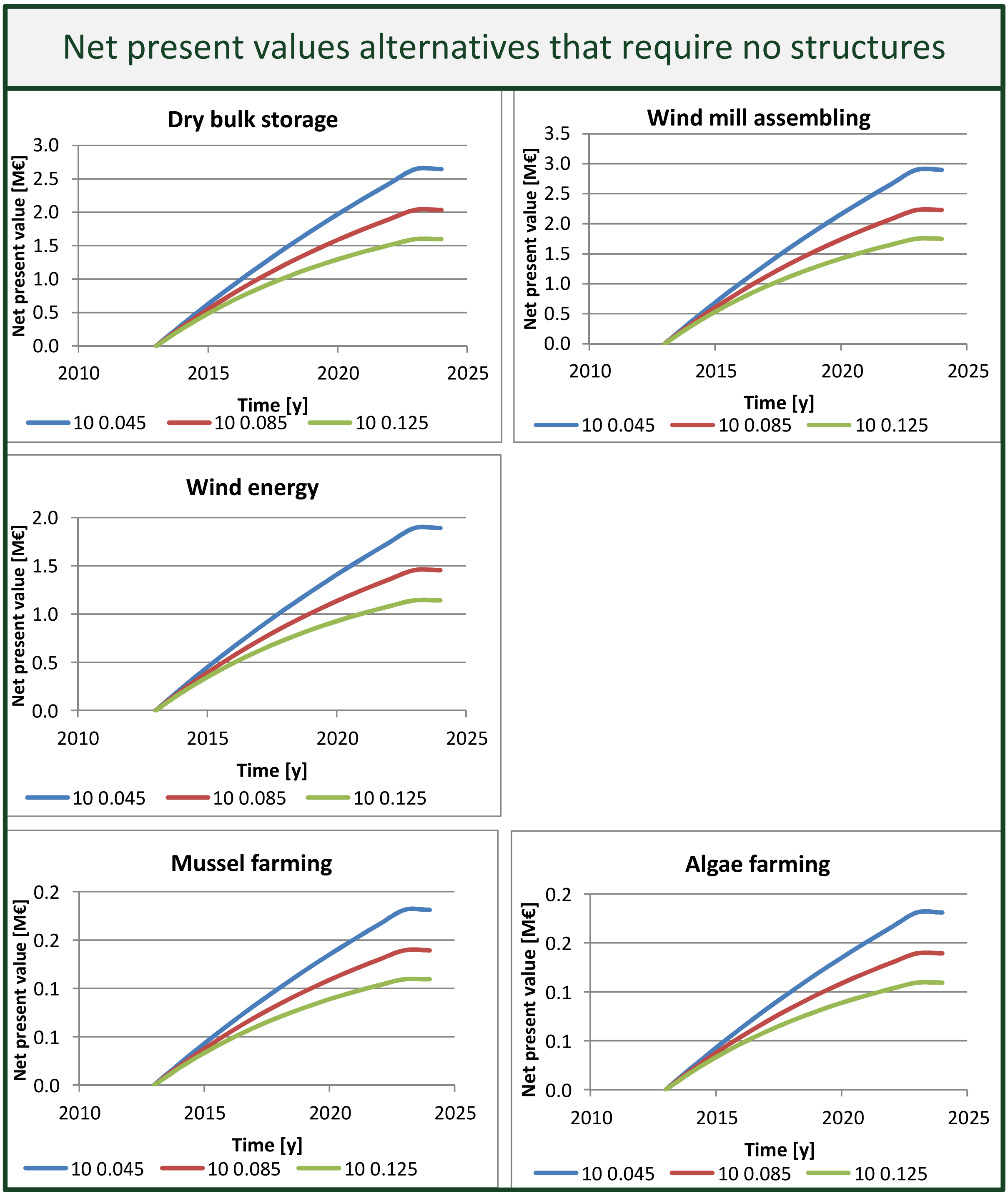


Figure A-4: Net present values of the alternatives that do not require structures by Port of Rotterdam Authority for different discount rates, i.e. 4.5% (blue, top line), 8.5% (red, middle line) and 12.5% (green, lower line)

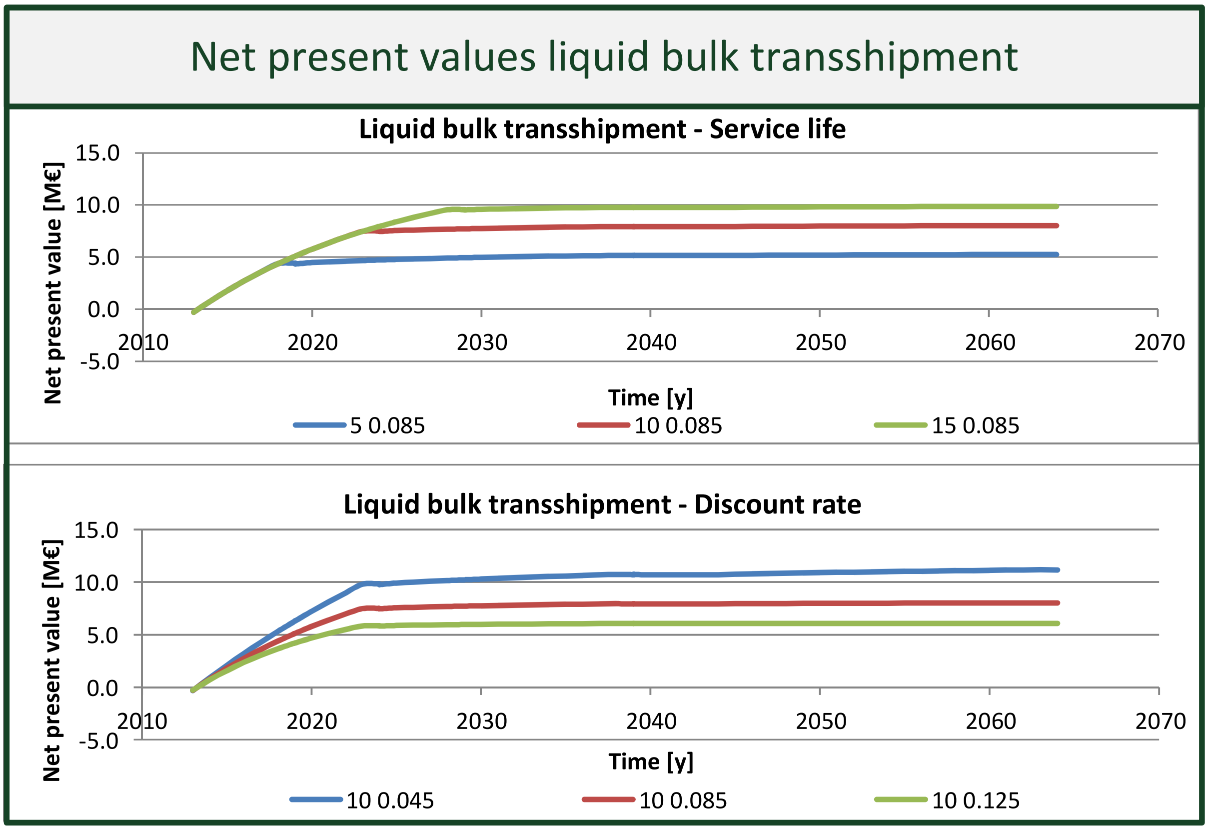


Figure A-5: Net present values liquid bulk transshipment; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

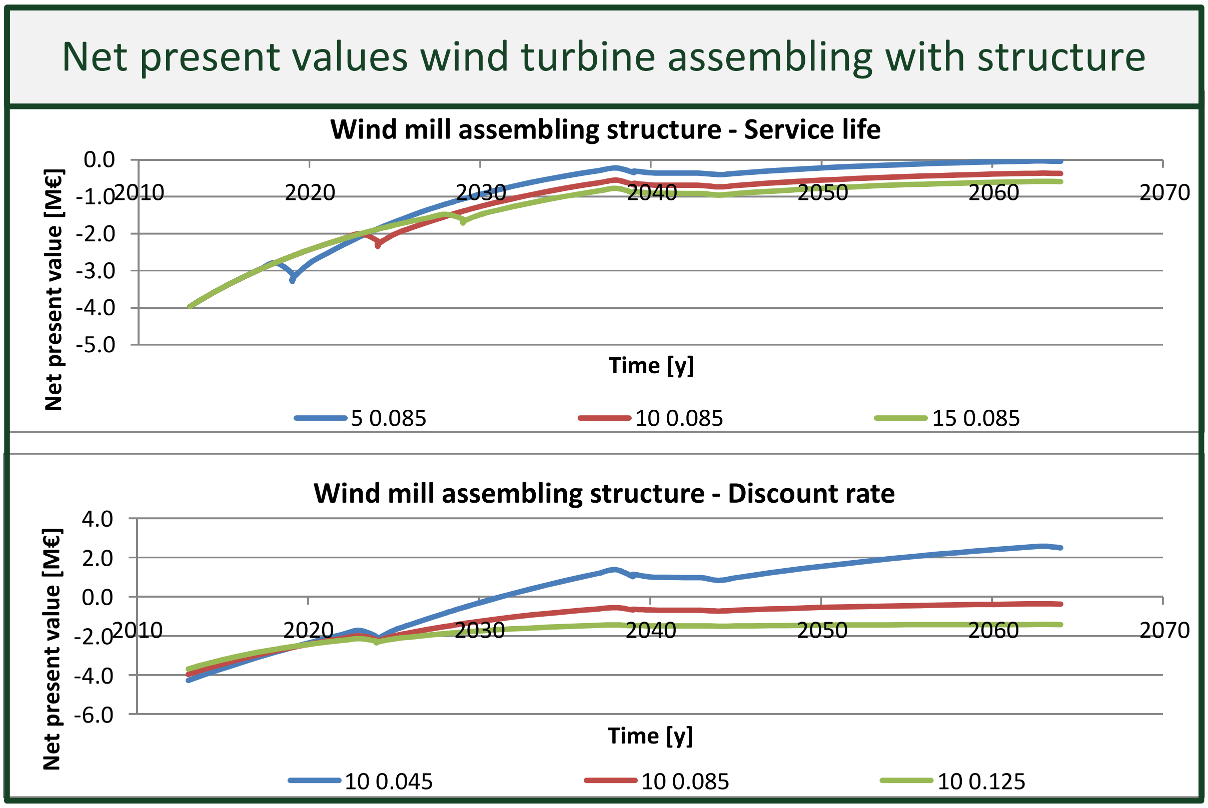


Figure A-6: Net present values wind mill assembling facility; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

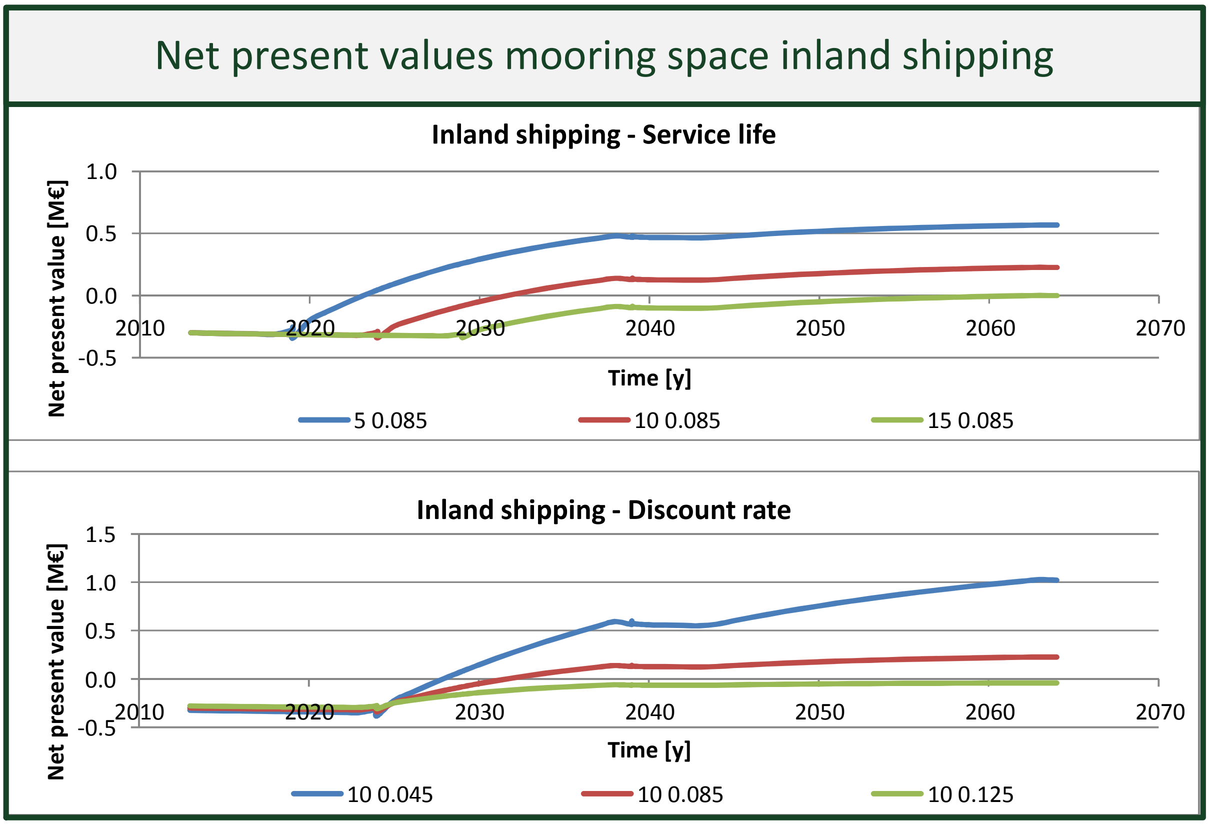


Figure A-7: Net present values mooring spaces inland shipping; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

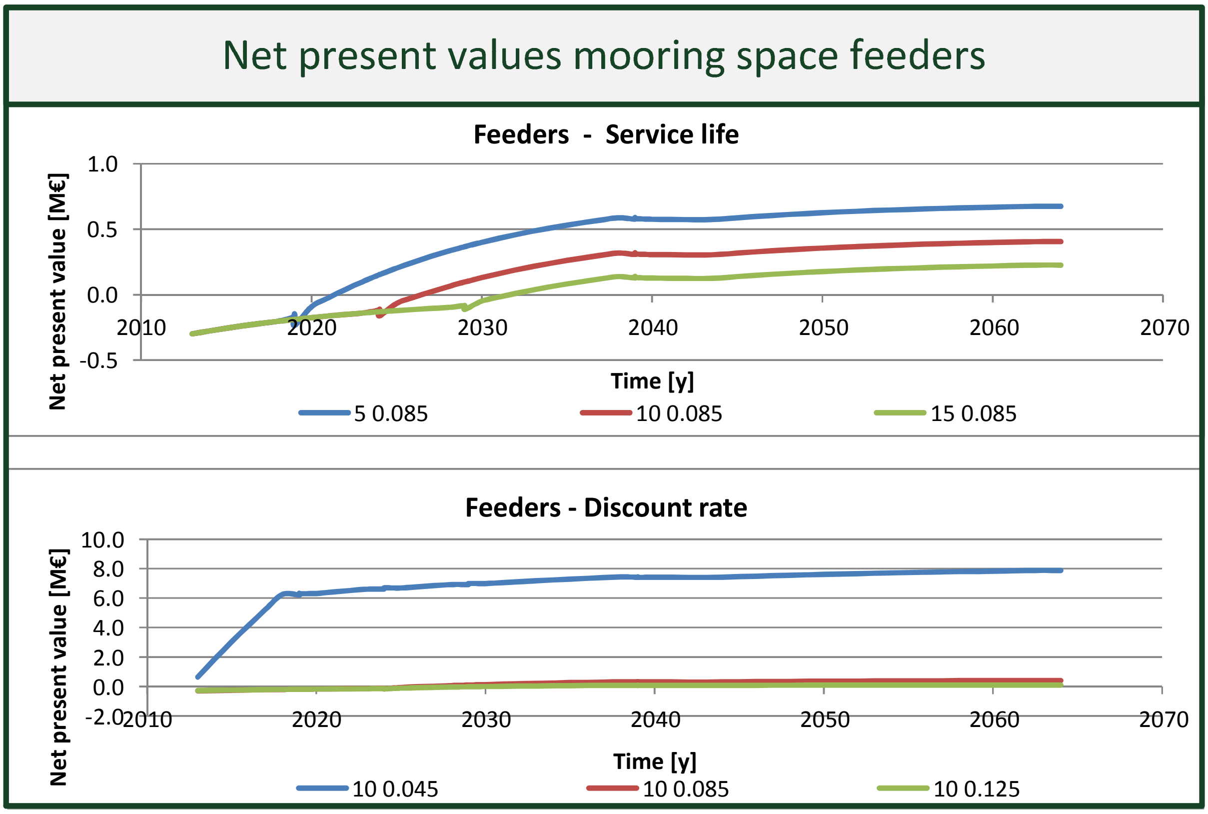


Figure A-8: Net present values mooring spaces feeders; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

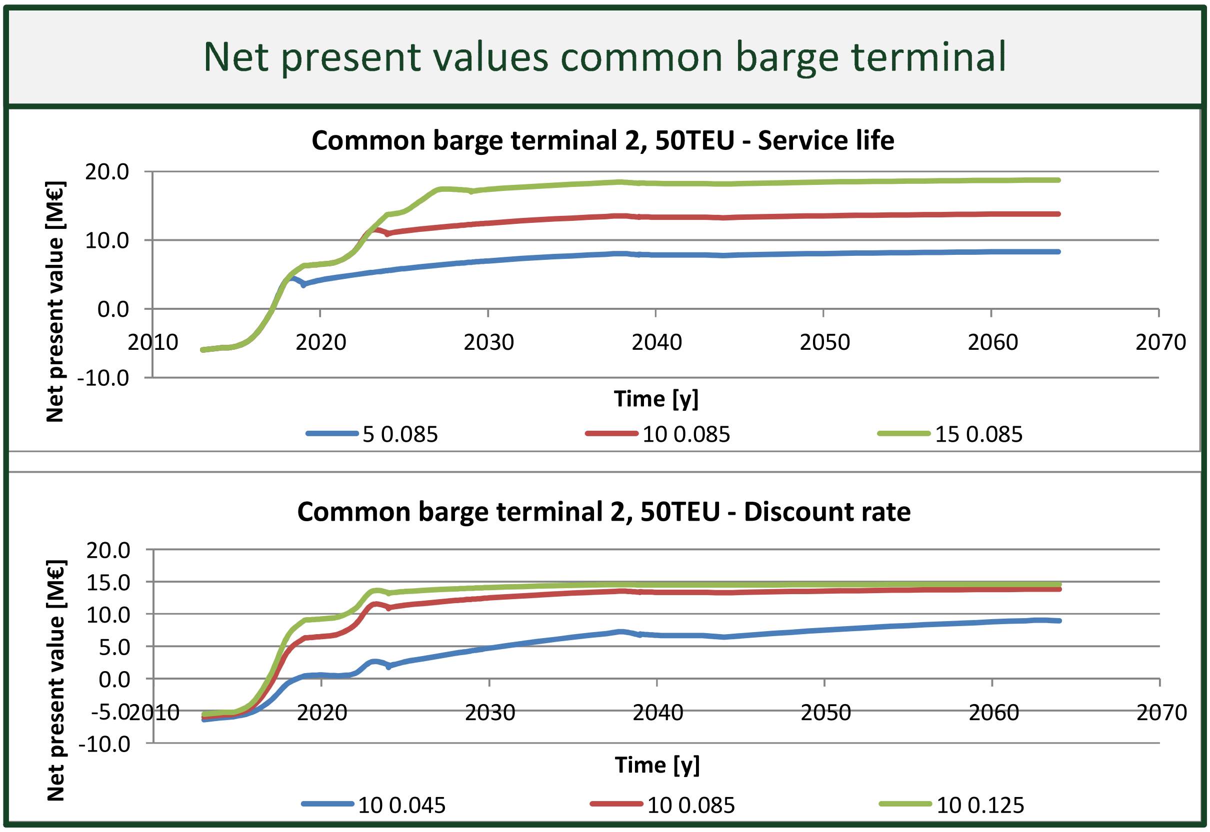


Figure A-9: Net present values common barge terminal; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

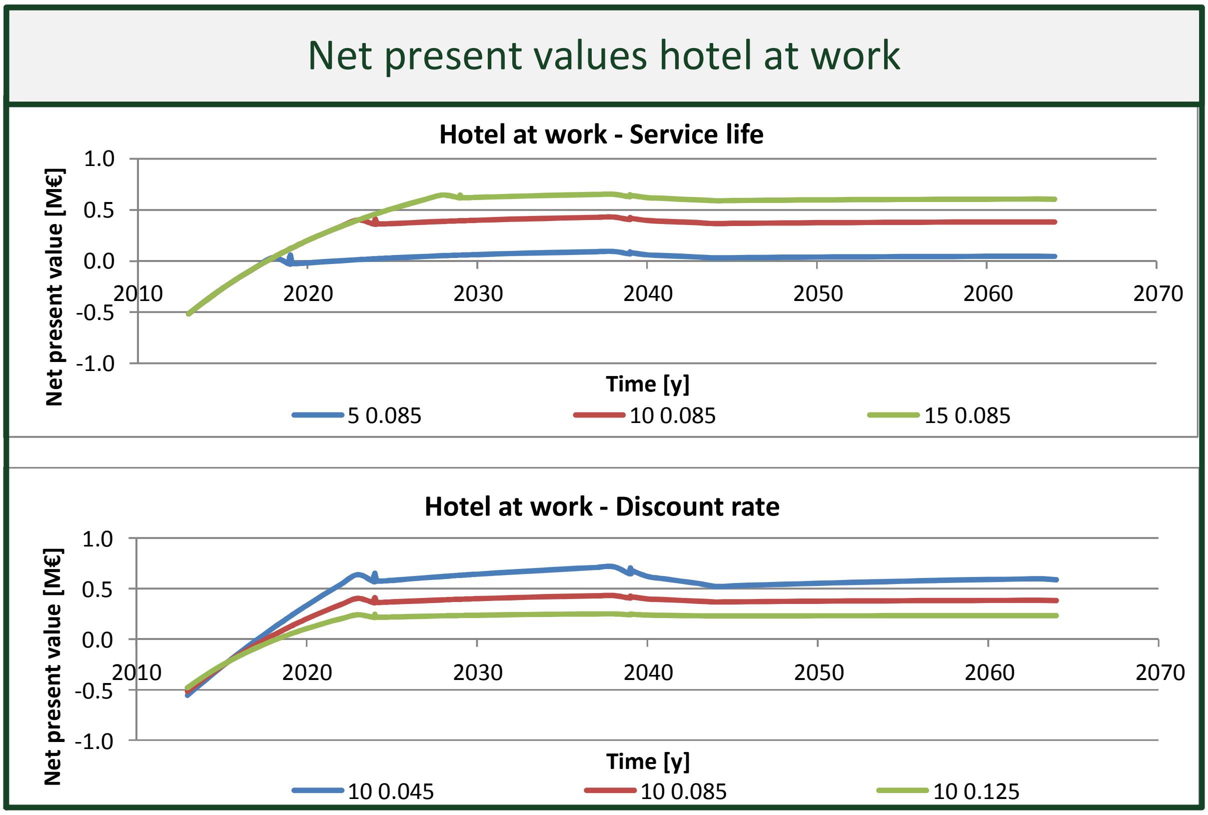


Figure A-10: Net present values hotel at work; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

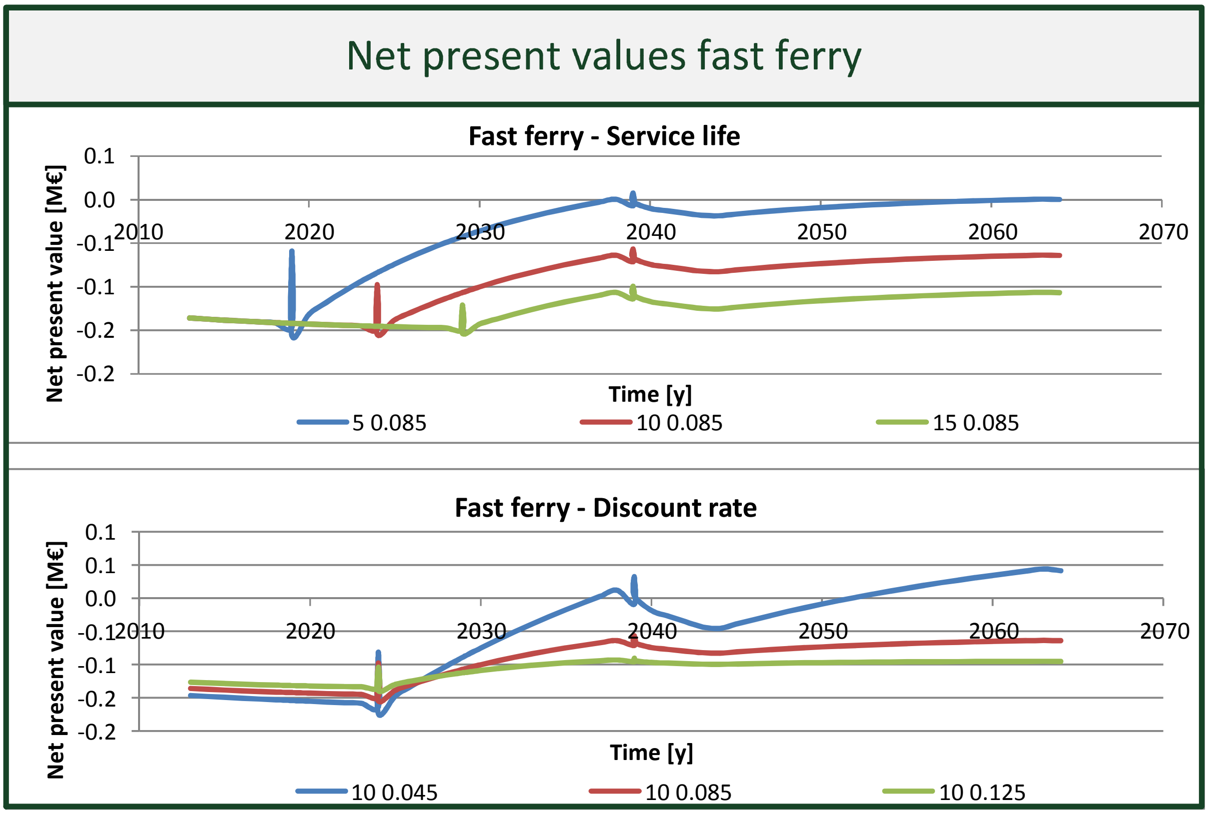


Figure A-11: Net present values fast ferry; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

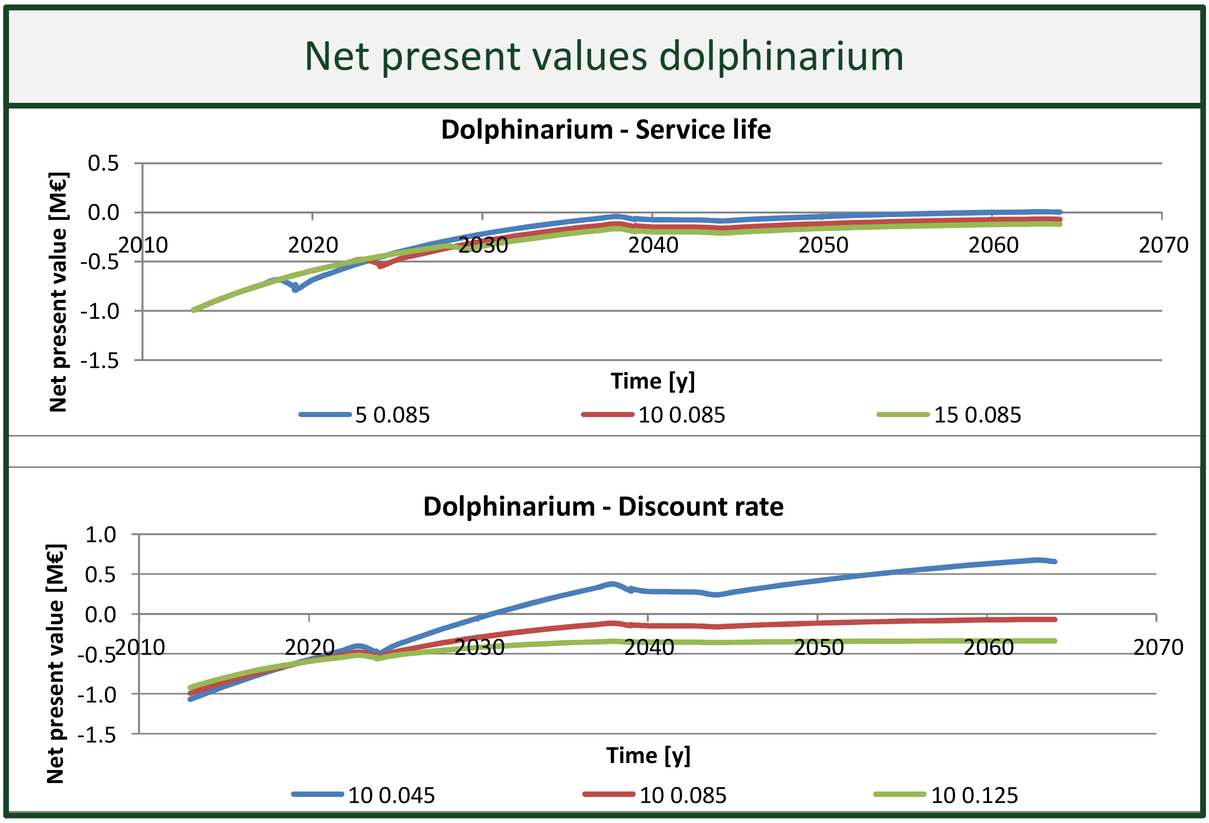


Figure A-12: Net present values dolphinarium; lower values (blue line), base case: discount rate 8.5%, service life 10 years (red line) and high values (green line)

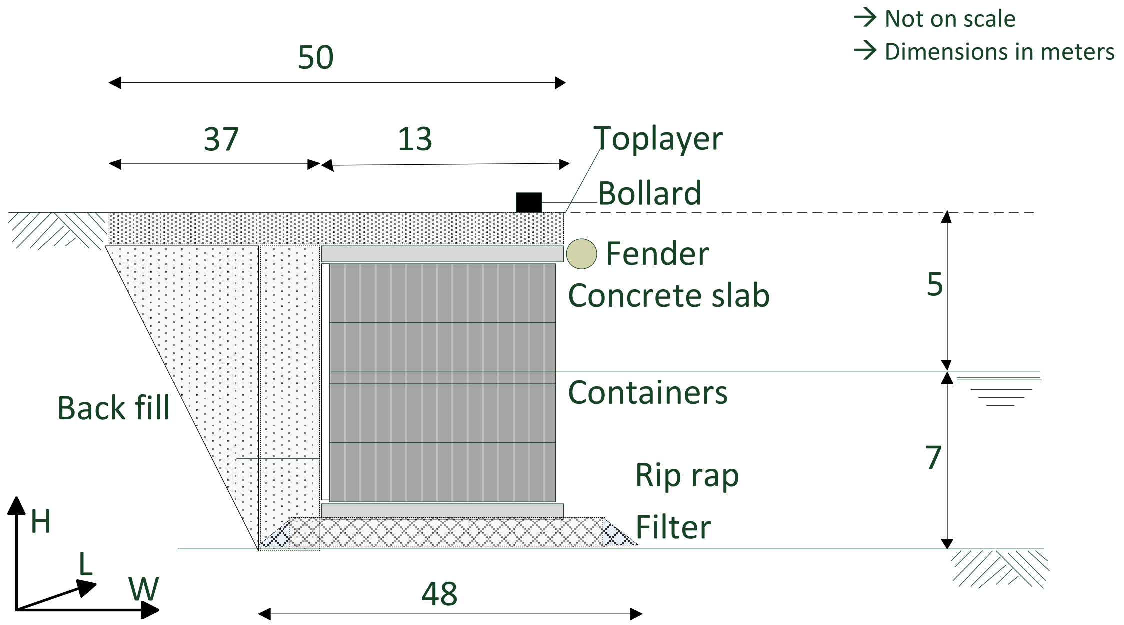
B Structures

B.1 Dimensions

General (applicable to all structures)

- Overall dimensions: Quay length = 50 m, width = 50 m, retaining height = 12 m (common barge terminal), 14 m (hotel at work)
- Filter layer: Width to right from quay = 30 m, height = 0.6 m (1 m in [69]).
- Top layer: height = 0.5 m (between 0.25 and 1 m in [45]).
- Displacement of sand (if required): width = 100 m, height = 6 m.
- Facing (if required) from the bottom to: 2/3 of the retaining height for common barge terminal and 2/3 of the water depth for hotel at work [42].
- Dimensions of piles are indicated by their circumference (L) and thickness (W)

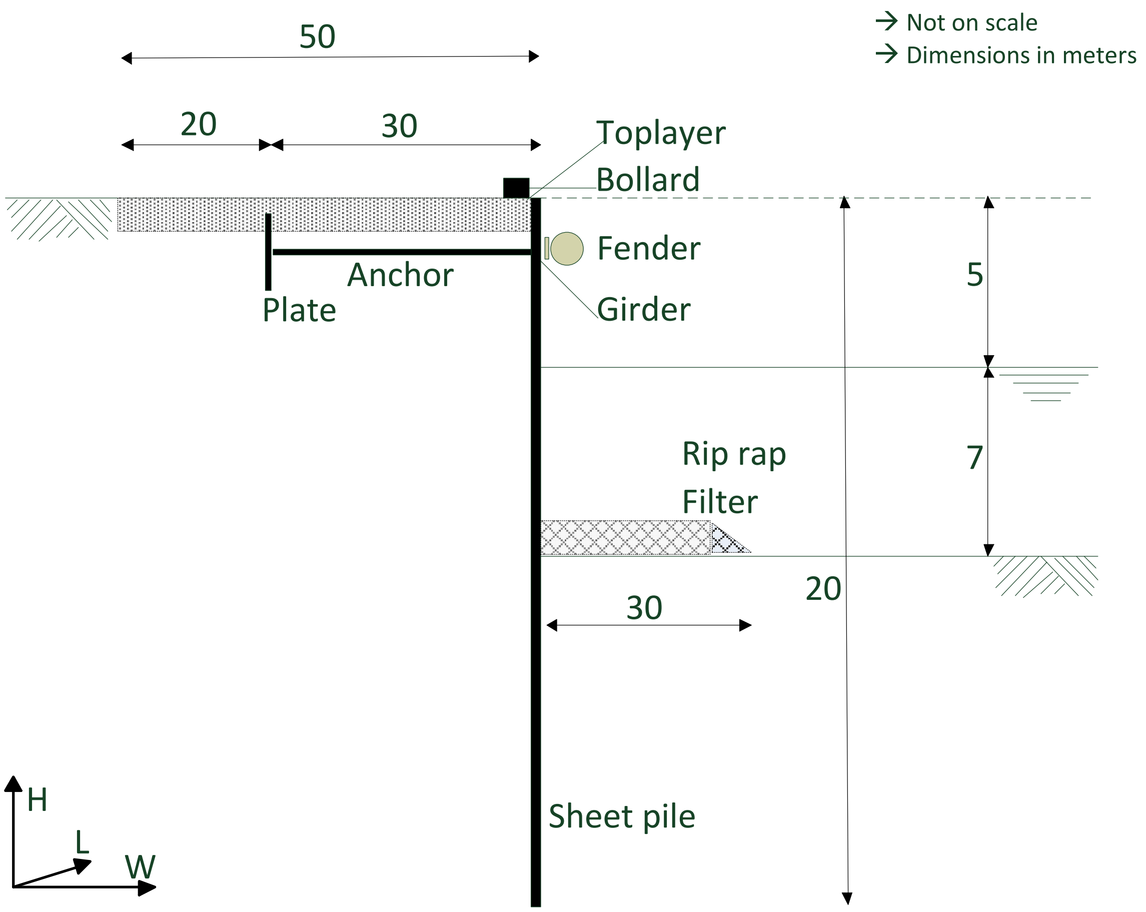
Dimensions Containerland



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Concrete	Concrete slab	15.00	3.33	13.00	0.50	1.00	324.68	m3
Container	Containers	160.00	1.00	1.00	1.00	1.00	160.00	p
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Steel	Hawsers	160.00	0.10	0.02	11.40	7.85	32.22	t
Stones	Filter	1.00	50.00	48.00	0.10	1.70	408.00	t
Stones	Riprap	1.00	50.00	48.00	0.50	1.70	2'040.00	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-1: Dimensions of Containerland for the common barge terminal, based on design pilot project in the Dintelhaven, Rotterdam [45]; it is assumed the containers are filled with sand and can withstand active soil pressures

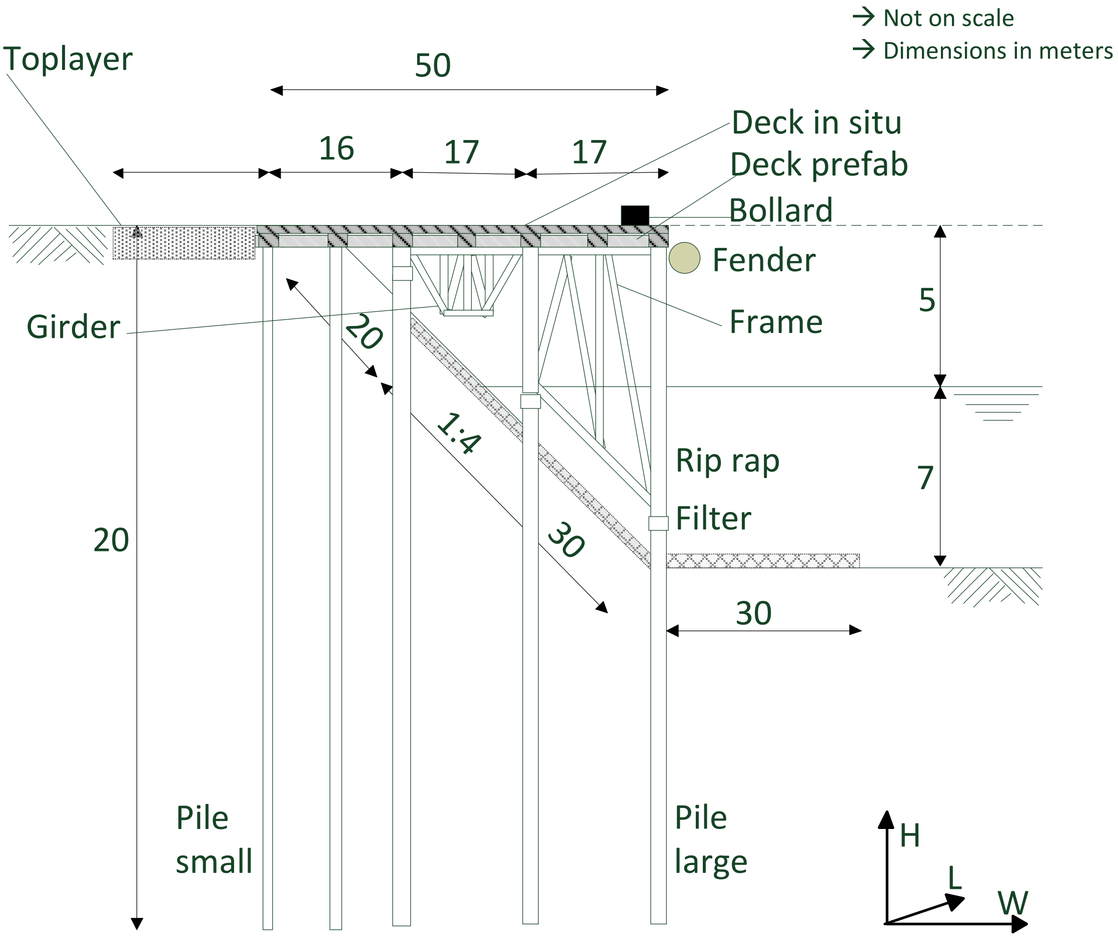
Dimensions sheet pile wall



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Steel	Anchor	50.00	0.31	0.01	30.00	7.85	36.99	t
Steel	Sheet pile	100.00	0.50	0.02	20.00	7.85	176.63	t
Steel	Anchor plate	1.00	50.00	0.02	8.00	7.85	70.65	t
Steel	Girder	1.00	50.00	0.02	1.00	7.85	5.89	t
Stones	Filter	1.00	50.00	30.00	0.10	1.70	255.00	t
Stones	Riprap	1.00	50.00	30.00	0.50	1.70	1'275.00	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-2: Dimensions of a sheet pile wall for the common barge terminal, based on design study temporary contractor quay wall on the inner lake, Maasvlakte 2, Rotterdam [69]

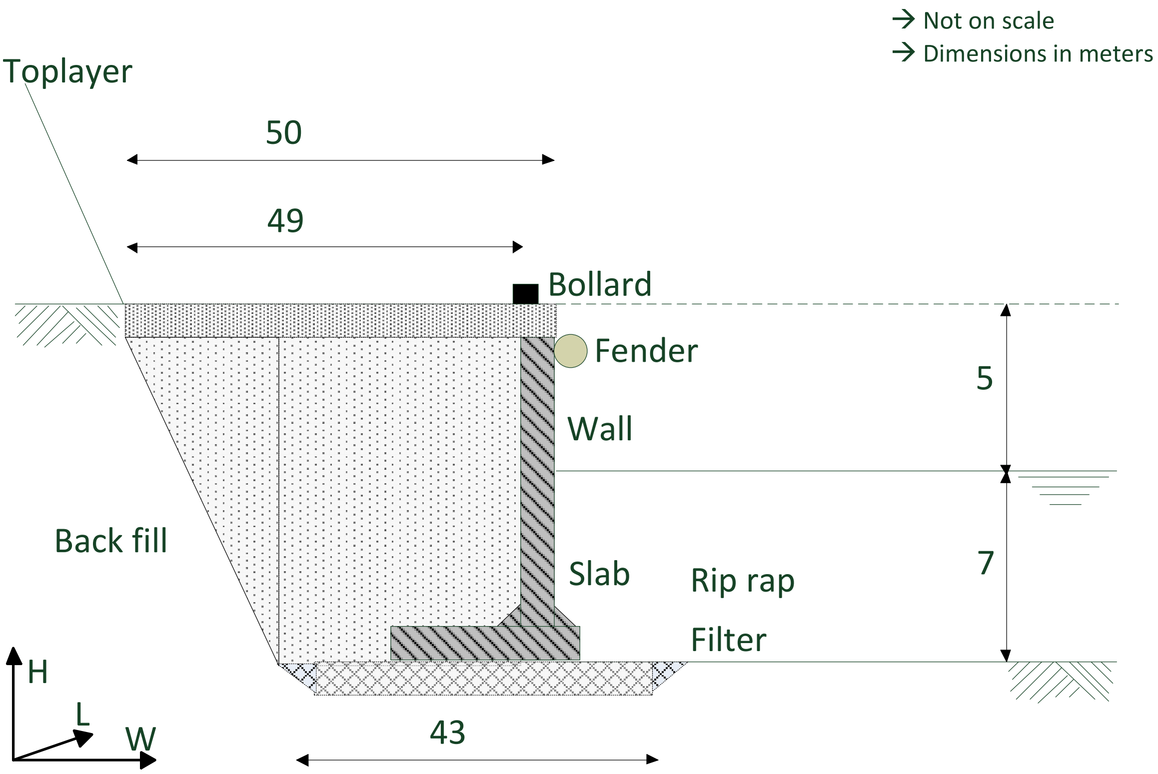
Dimensions Maxisteck



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Concrete	Deck prefab	9.00	8.33	8.33	0.25	1.00	156.13	m3
Concrete	Deck in situ	3.00	16.67	16.67	0.25	1.00	208.42	m3
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Steel	Frame cross	24.00	1.57	0.02	9.00	7.85	39.95	t
Steel	Frame long high	24.00	1.57	0.02	4.50	7.85	19.98	t
Steel	Frame long low	9.00	1.57	0.02	9.00	7.85	14.98	t
Steel	Girder	117.00	1.57	0.02	4.50	7.85	97.38	t
Steel	Pile small	12.00	1.57	0.02	20.00	7.85	44.39	t
Steel	Pile small frame	12.00	1.57	0.02	6.00	7.85	13.32	t
Steel	Pile large	9.00	3.14	0.02	20.00	7.85	88.78	t
Steel	Pile large frame	9.00	3.14	0.02	6.00	7.85	26.63	t
Stones	Filter	1.00	50.00	60.00	0.10	1.70	510.00	t
Stones	Riprap	1.00	50.00	60.00	0.50	1.70	2'550.00	t
Stones	Toplayer	1.00	50.00	0.00	0.50	1.70	0.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-3: Dimensions of Maxisteck for the common barge terminal, based on preliminary design study for innovative quay in the Brittaniehaven, Rotterdam [34]

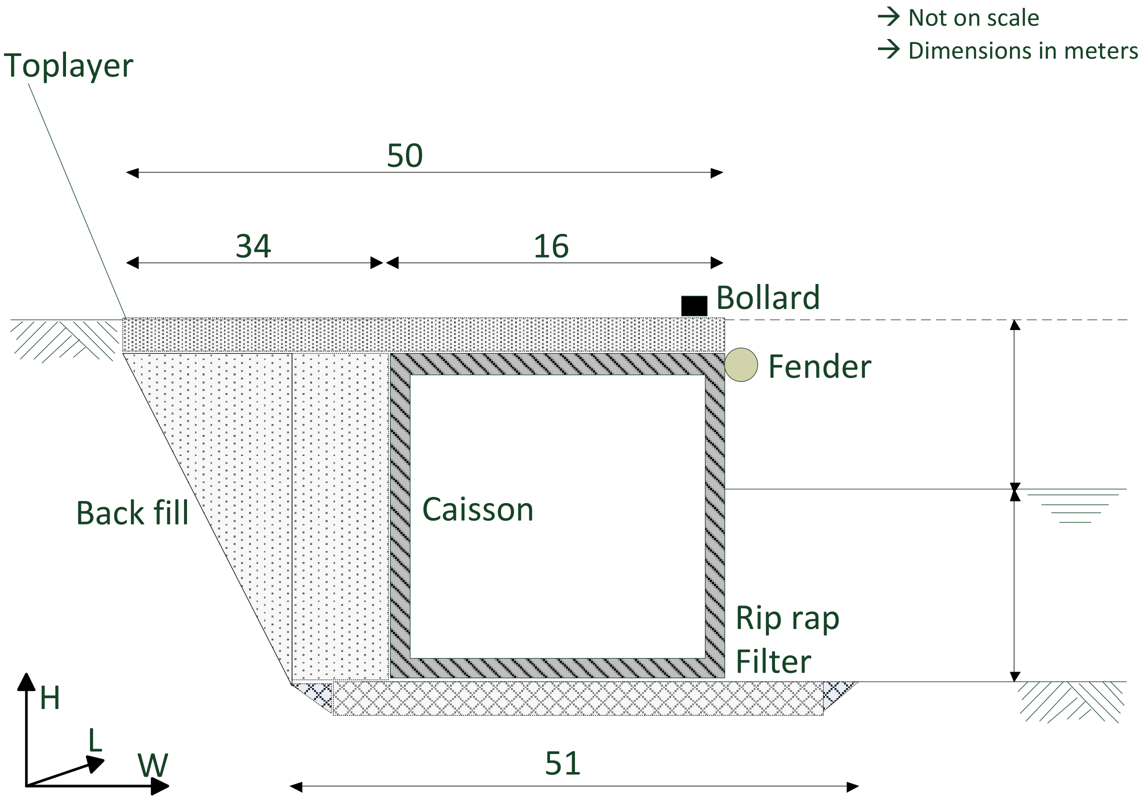
Dimensions L wall



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Concrete	Slab	10.00	5.00	10.00	1.00	1.00	500.00	m3
Concrete	Wall	10.00	5.00	1.00	11.00	1.00	550.00	m3
Sand	Back fill	1.00	50.00	41.00	5.00	1.00	10'250.00	m3
Sand	Back fill	1.00	50.00	8.00	10.00	1.00	4'000.00	m3
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Stones	Filter	1.00	50.00	43.00	0.10	1.70	365.50	t
Stones	Riprap	1.00	50.00	43.00	0.50	1.70	1'827.50	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-4: Dimensions of an L wall for the common barge terminal, dimensions of the wall and slab are based on dimensions of the caisson

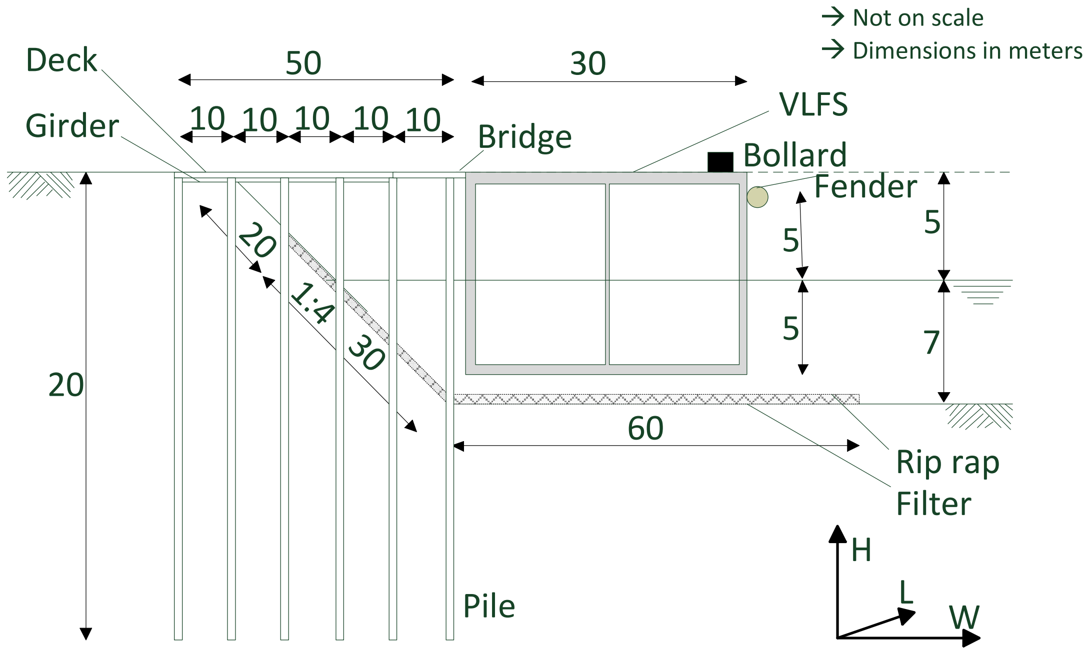
Dimensions caisson



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Concrete	Walls inner	8.00	1.00	14.00	8.00	1.00	896.00	m3
Concrete	Walls top	4.00	1.00	16.00	10.00	1.00	640.00	m3
Concrete	Slabs	4.00	25.00	16.00	1.00	1.00	1'600.00	m3
Concrete	Walls side	4.00	25.00	1.00	10.00	1.00	1'000.00	m3
Sand	Back fill	1.00	50.00	34.00	5.50	1.00	9'350.00	m3
Sand	Back fill	1.00	50.00	2.00	11.00	1.00	1'100.00	m3
Sand	Ballast	1.00	50.00	14.00	10.00	1.00	7'000.00	m3
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Stones	Filter	1.00	50.00	51.00	0.10	1.70	433.50	t
Stones	Riprap	1.00	50.00	51.00	0.50	1.70	2'167.50	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-5: Dimensions of a caisson for the common barge terminal, based on preliminary design floating factory Maasvlakte 2 caisson breakwater [28]

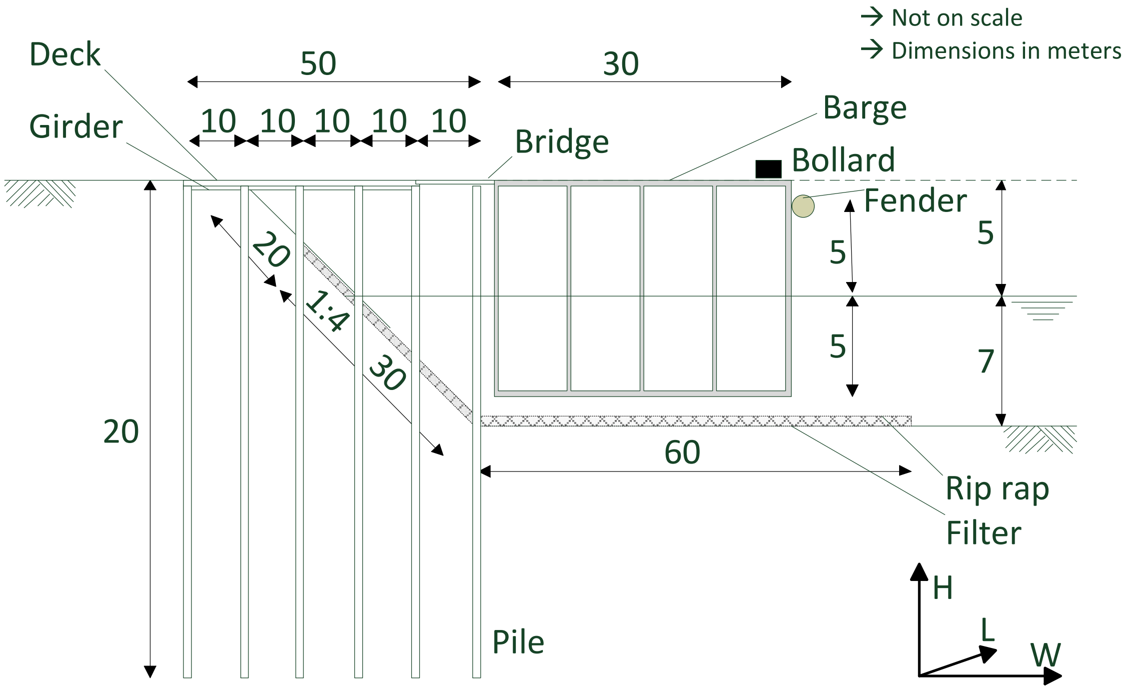
Dimensions very large floating structure



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Concrete	Walls inner	8.00	0.20	28.50	14.50	1.00	661.20	m3
Concrete	Walls top	2.00	0.75	30.00	16.00	1.00	720.00	m3
Concrete	Slabs	2.00	50.00	30.00	0.75	1.00	2'250.00	m3
Concrete	Walls side	2.00	50.00	0.75	16.00	1.00	1'200.00	m3
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Steel	Mooring piles	2.00	6.28	0.02	30.00	7.85	59.19	t
Steel	Pile	12.00	0.79	0.02	20.00	7.85	29.59	t
Steel	Deck	50.00	2.50	1.00	0.01	7.85	4.91	t
Steel	Girder small	11.00	2.50	0.01	0.25	7.85	0.54	t
Steel	Girder diagonal	20.00	10.00	0.01	0.10	7.85	0.79	t
Steel	Girder long	10.00	10.00	0.01	0.50	7.85	3.93	t
Stones	Filter	1.00	50.00	60.00	0.10	1.70	510.00	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	m3
Stones	Riprap	1.00	50.00	60.00	0.50	1.70	2'550.00	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-6: Dimensions of a very large floating structure for the common barge terminal, jetty (over full quay length) verified with preliminary design Rapid Bay [9], very large floating structure based on freeboard (requirement = 5 m, design = 4.3 m)

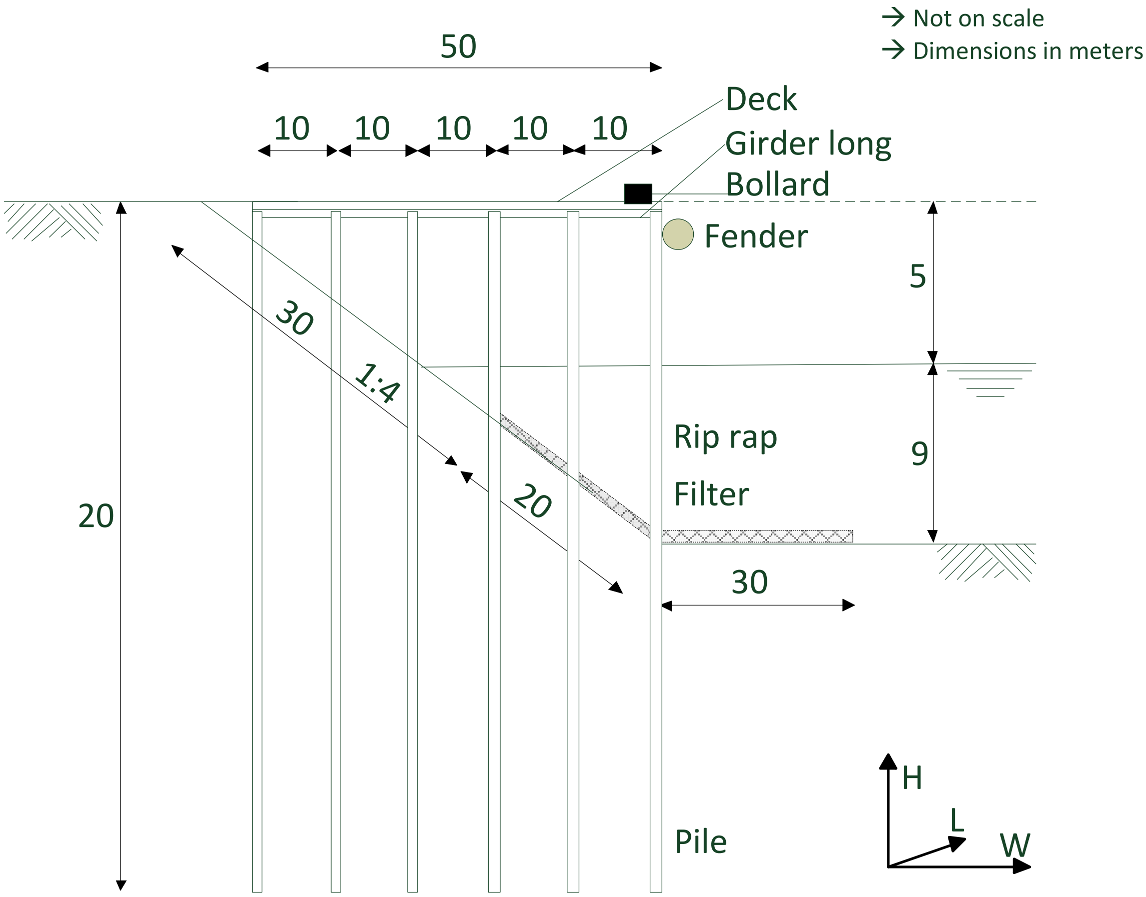
Dimensions barge



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Sand	Sand displace	1.00	50.00	100.00	6.00	1.00	30'000.00	m3
Steel	Mooring piles	2.00	6.28	0.02	30.00	7.85	59.19	t
Steel	Walls inner	3.00	0.02	50.00	11.00	7.85	259.05	t
Steel	Walls top	2.00	0.05	30.00	11.00	7.85	259.05	t
Steel	Slabs	2.00	50.00	30.00	0.05	7.85	1'177.50	t
Steel	Walls side	2.00	50.00	0.05	11.00	7.85	431.75	t
Steel	Pile	12.00	0.79	0.02	20.00	7.85	29.59	t
Steel	Deck	50.00	2.50	1.00	0.01	7.85	4.91	t
Steel	Girder small	11.00	2.50	0.01	0.25	7.85	0.54	t
Steel	Girder diagonal	20.00	10.00	0.01	0.10	7.85	0.79	t
Steel	Girder long	10.00	10.00	0.01	0.50	7.85	3.93	t
Stones	Filter	1.00	50.00	90.00	0.10	1.70	765.00	t
Stones	Riprap	1.00	50.00	90.00	0.50	1.70	3'825.00	t
Stones	Toplayer	1.00	50.00	50.00	0.50	1.70	2'125.00	m3
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	m
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	m

Figure B-7: Dimensions of a barge for the common barge terminal, jetty (over full quay length) verified with preliminary design Rapid Bay [9], barge based on freeboard (requirement = 5 m, design = 5.5 m)

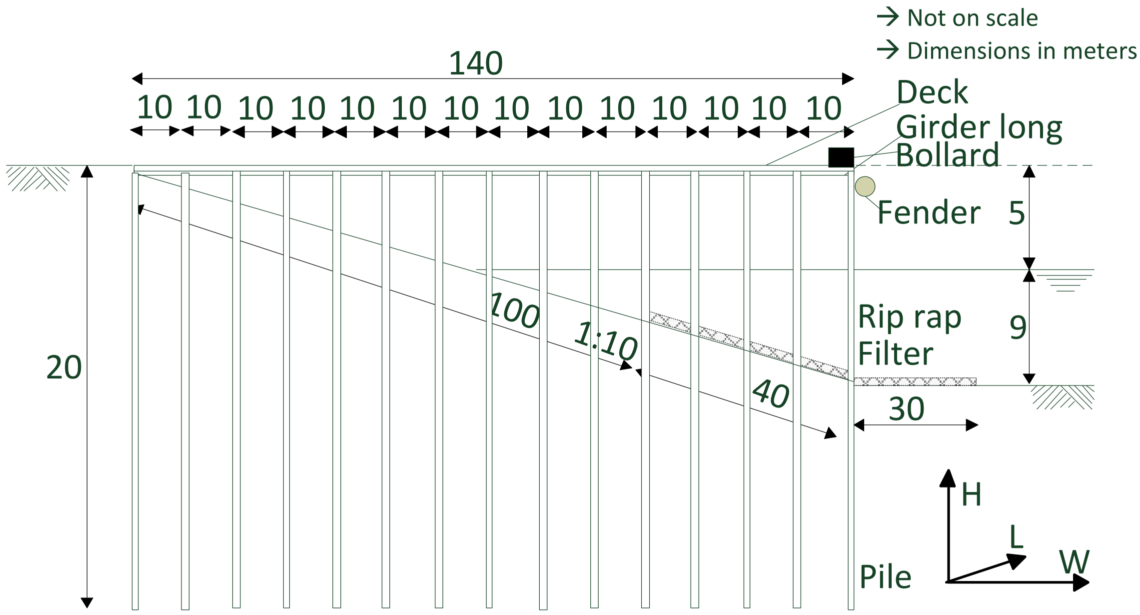
Dimensions jetty on slope of 1/4 (with facing)



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Steel	Pile	30.00	0.79	0.02	20.00	7.85	73.98	t
Steel	Deck	140.00	2.50	1.00	0.01	7.85	13.74	t
Steel	Girder small	71.00	2.50	0.01	0.25	7.85	3.48	t
Steel	Girder diagonal	140.00	10.00	0.01	0.10	7.85	5.50	t
Steel	Girder long	70.00	10.00	0.01	0.50	7.85	27.48	t
Stones	Filter	1.00	20.00	70.00	0.10	1.70	238.00	t
Stones	Riprap	1.00	20.00	70.00	0.50	1.70	1'190.00	t
Supra	Bollards	1.00	100.00	1.00	1.00	1.00	100.00	m
Supra	Fenders	1.00	100.00	1.00	1.00	1.00	100.00	m

Figure B-8: Dimensions of a jetty on a slope of 1/4 with facing for hotel at work, verified with preliminary design Rapid Bay [9]

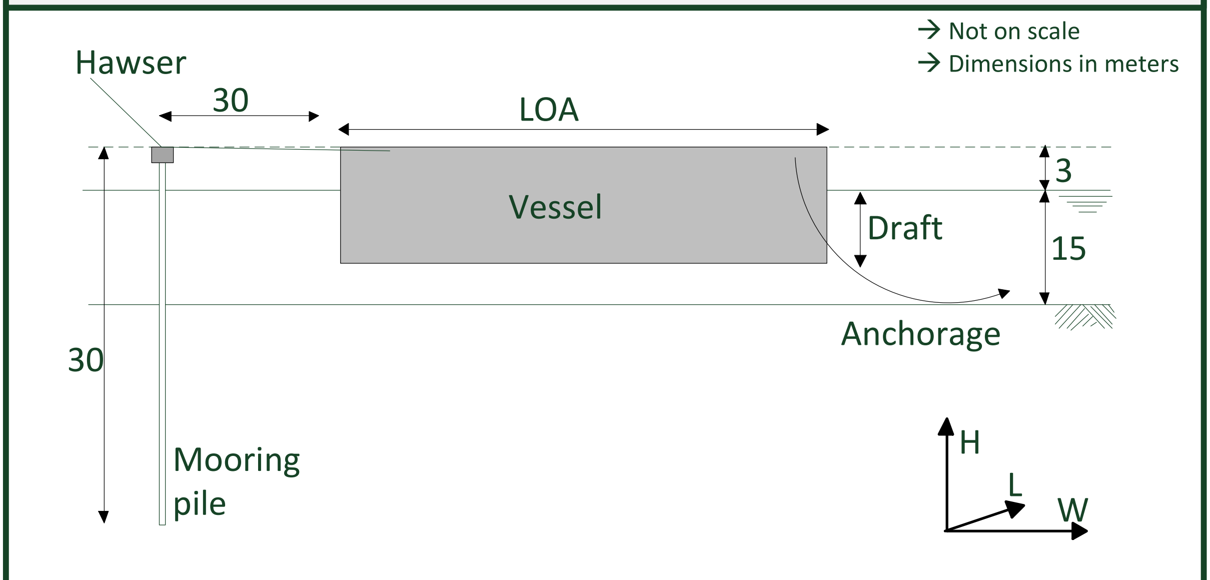
Dimensions jetty on (natural) slope of 1/10



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Sand	Sand displace	1.00	20.00	50.00	6.00	1.00	6'000.00	m3
Steel	Pile	12.00	0.79	0.02	20.00	7.85	29.59	t
Steel	Deck	50.00	2.50	1.00	0.01	7.85	4.91	t
Steel	Girder small	11.00	2.50	0.01	0.25	7.85	0.54	t
Steel	Girder diagonal	20.00	10.00	0.01	0.10	7.85	0.79	t
Steel	Girder long	10.00	10.00	0.01	0.50	7.85	3.93	t
Stones	Filter	1.00	20.00	50.00	0.10	1.70	170.00	t
Stones	Riprap	1.00	20.00	50.00	0.50	1.70	850.00	t
Supra	Bollards	1.00	100.00	1.00	1.00	1.00	100.00	m
Supra	Fenders	1.00	100.00	1.00	1.00	1.00	100.00	m

Figure B-9: Dimensions of a jetty on a slope of 1/10 for hotel at work, verified with preliminary design Rapid Bay [9]

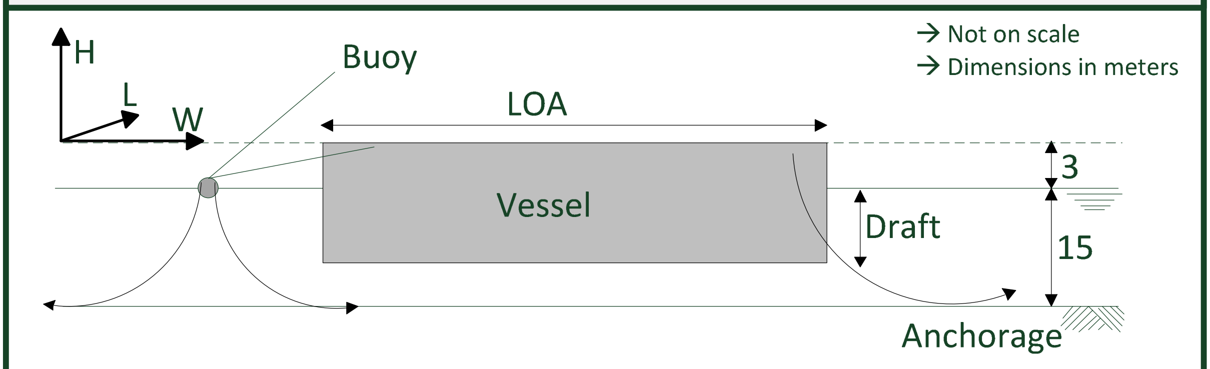
Dimensions dolphin



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Steel	Mooring piles	2.00	6.28	0.02	30.00	7.85	59.19	t
Supra	Bollards	1.00	50.00	1.00	1.00	1.00	50.00	p
Supra	Fenders	1.00	50.00	1.00	1.00	1.00	50.00	p

Figure B-10: Side view of a dolphin for liquid bulk transshipment, number and dimensions based on interviews [42][49]

Dimensions buoy



Part	Element	Number	L [m]	W [m]	H [m]	Factor	Quantity	Unit
Buoy	Pile	2.00	1.00	1.00	1.00	1.00	2.00	p

Figure B-11: Side view of a buoy for liquid bulk transshipment, number based on interview [42]

B.2 Net present values

Cost components per structure

The investment costs of the structures are calculated using unit prices *(in Section 7.2.1)*, quantities *(see Appendix B.1)*, a transport factor (1.25 for large prefabricated structures) and an overhead factor (1.6). These components differ per structure *(see Figure B-12).*

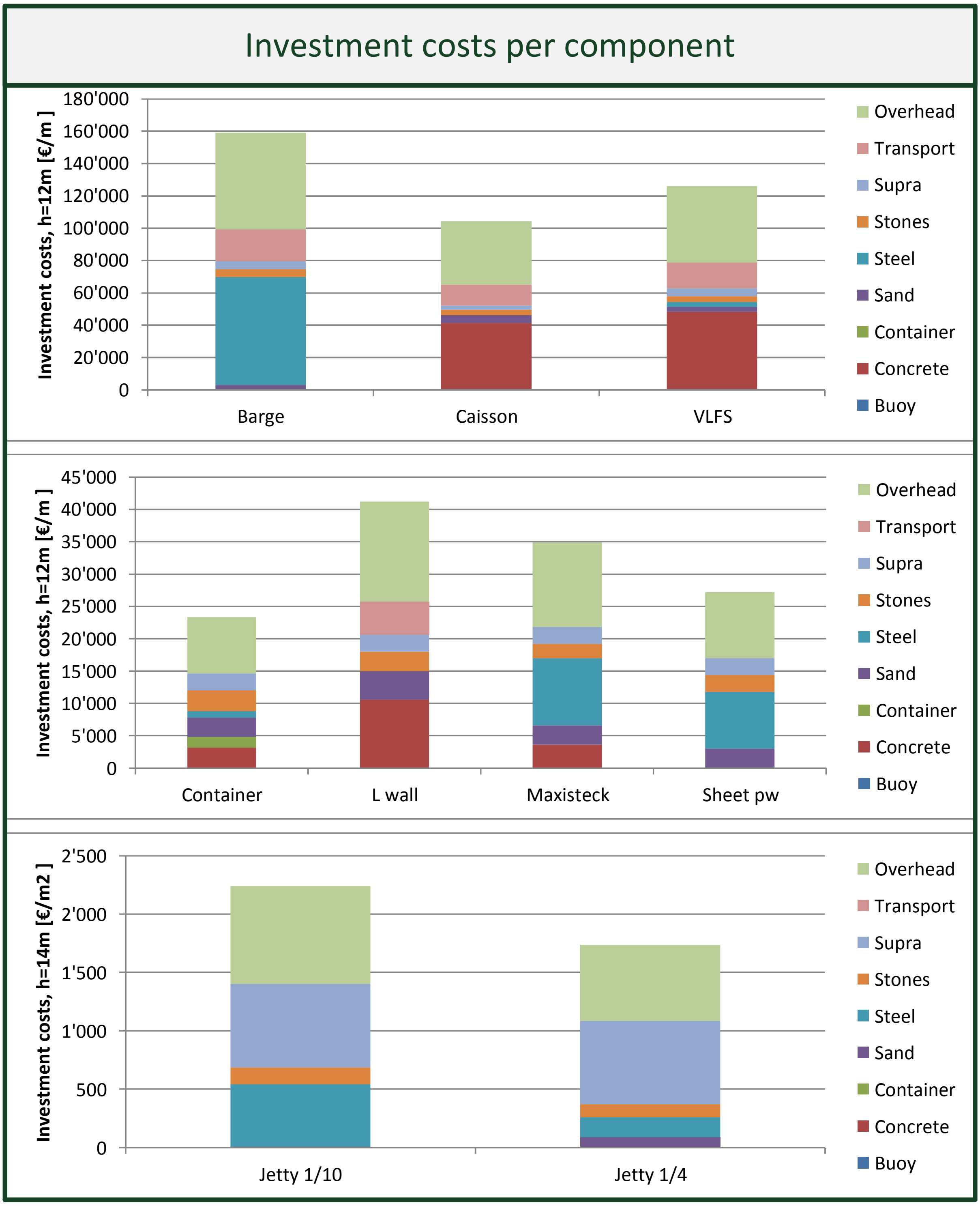


Figure B-12: Cost components per structure, each component represents one part of the column

Cost comparison
The investment costs of the structures are calculated using assumptions *(see Section 7.2.1 and Appendix B.1)*. A comparison of the investment costs of this research with key figures of other projects indicates whether estimations are within a reasonable bandwidth [19]. The investment costs of the structures *(previous page)* are divided by the overhead factor in order to compare with the key figures. The differences are smaller than 30% *(see Figure B-13):*

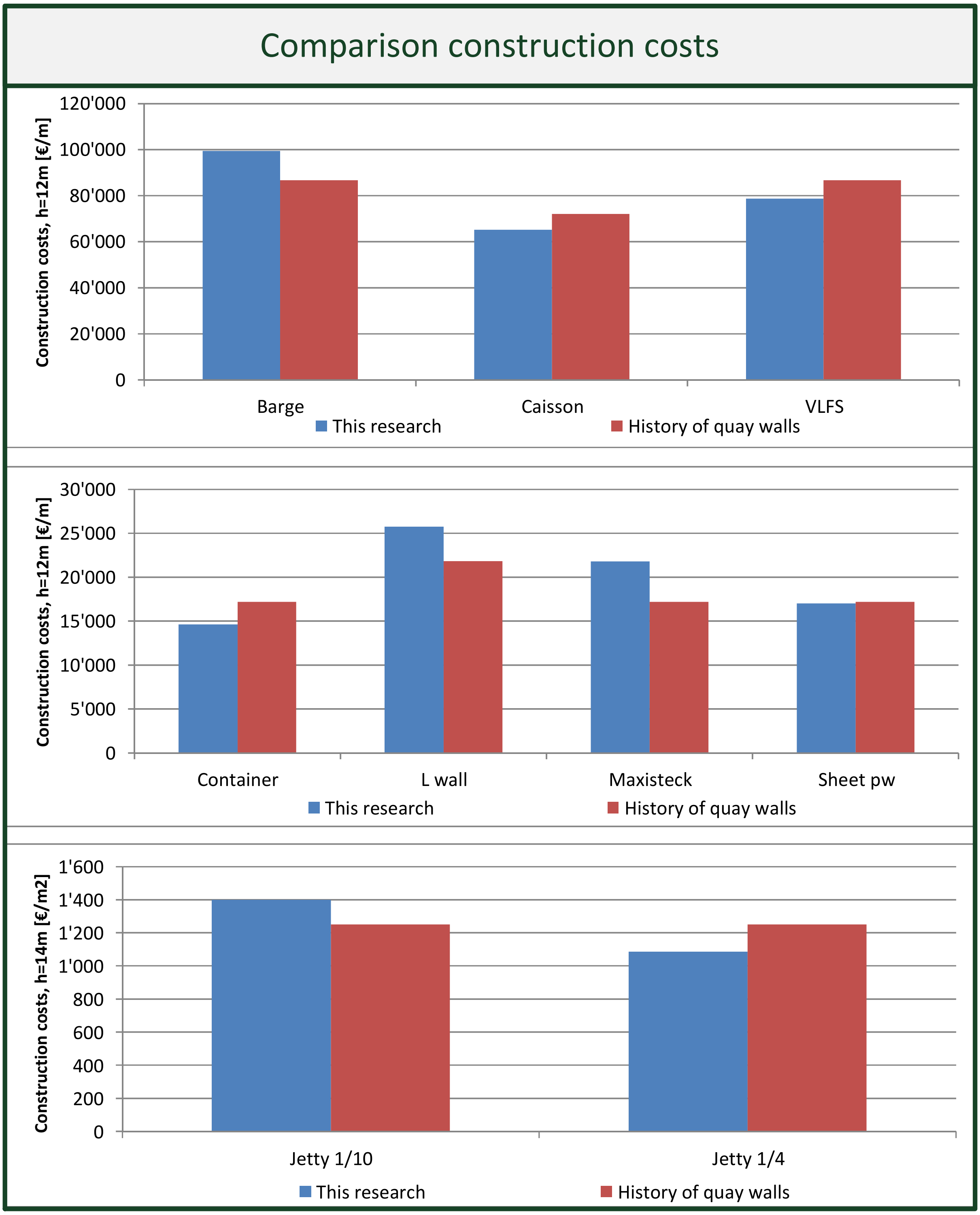


Figure B-13: Cost comparison this research (blue, left column) with history of quay walls per structure (red, right column)

Set up spreadsheet scenarios

The net present values are calculated for several scenarios and input parameters. The different cost and revenue parameters are assigned and discounted over time in a spreadsheet *(see Table B-2 and Table B-3).*

Abbreviations (1/2)	
Parameter	**Definition**
CBT	Net present cost savings
CF0,1,2,3,4	Discounted parameter in scenario
DC	Demolition costs
df	Discount factor
dr	Discount rate
IC	Investment costs
NPV	Net present value
OC	Operational costs
OUT	No parameter
P0,1,2,3,4	Parameter that taken into account
RA	Additional revenues
RC	Demobilization costs

Abbreviations (2/2)	
Parameter	**Definition**
RC10	Replacement component after 10 y
RC20	Replacement component after 20 y
RC25	Replacement component after 25 y
RC30	Replacement component after 30 y
RC40	Replacement component after 40 y
RI	Revenues
RV10	Rest value after 10 years
RV25	Rest value after 25 years
SC	Storage costs
sl	Service life
	NPV scenario 2, 4 (sell)
	NPV scenario 1,3,5 (demolition)

Table B-1: Abbrevations of the parameters used in the spreadsheet to calculate the net present values for several scenarios and input parameters

Set up spreadsheet (1/2)											
P0	**P1**	**P2**	**P3**	**P4**	**Year**	**CF0**	**CF1**	**CF2**	**CF3**	**CF4**	**NPV**
OUT	OUT	OUT	IC	OUT	2013	0	0	0	-5'952'983	0	-5'952'983
CBT	RI	OC	OUT	OUT	2014	0	326'473	-54'866	0	0	-5'681'376
CBT	RI	OC	OUT	OUT	2015	0	300'896	-50'568	0	0	-5'431'048
CBT	RI	OC	OUT	OUT	2016	1'109'038	277'324	-46'606	0	0	-4'091'293
CBT	RI	OC	OUT	OUT	2017	3'273'042	255'598	-42'955	0	0	-605'608
CBT	RI	OC	OUT	OUT	2018	2'005'509	235'574	-39'590	0	0	1'595'886
CBT	RI	OC	OUT	OUT	2019	0	217'119	-36'489	0	0	1'776'517
CBT	RI	OC	OUT	OUT	2019	0	217'119	-36'489	0	0	1'776'517
CBT	RI	OC	OUT	OUT	2019	0	217'119	-36'489	0	0	1'776'517
CBT	RI	OC	OUT	OUT	2020	193'399	200'110	-33'630	0	0	2'136'396
CBT	RI	OC	OUT	OUT	2021	858'340	184'433	-30'995	0	0	3'148'173
CBT	RI	OC	OUT	OUT	2022	2'219'017	169'984	-28'567	0	0	5'508'608
CBT	RI	OC	OUT	OUT	2023	2'804'815	156'668	-26'329	0	0	8'443'761
OUT	RA	OC	RC	RC10	2024	0	332'418	-24'267	-606'663	0	8'145'250
OUT	OUT	OUT	RC	RV10	2024	0	0	0	-606'663	60'943	7'898'042
OUT	OUT	OUT	DC	OUT	2024	0	0	0	-424'664	0	8'019'097

Table B-2: Set up the spreadsheet used to calculate the net present value for several scenarios and input parameters; common barge terminal using Containerland (five scenarios, service life of the inner lake of 10 years and discount rate of 8.5%)

Set up spreadsheet (2/2)											
P0	P1	P2	P3	P4	Year	CF0	CF1	CF2	CF3	CF4	NPV
OUT	RA	OC	OUT	OUT	2025	0	306'376	-22'365	0	0	8'429'261
OUT	RA	OC	OUT	OUT	2026	0	282'374	-20'613	0	0	8'691'022
OUT	RA	OC	OUT	OUT	2027	0	260'253	-18'998	0	0	8'932'276
OUT	RA	OC	OUT	OUT	2028	0	239'864	-17'510	0	0	9'154'630
OUT	RA	OC	OUT	OUT	2029	0	221'073	-16'138	0	0	9'359'565
OUT	RA	OC	OUT	OUT	2029	0	221'073	-16'138	0	0	9'359'565
OUT	RA	OC	OUT	OUT	2029	0	221'073	-16'138	0	0	9'359'565
OUT	RA	OC	OUT	OUT	2030	0	203'754	-14'874	0	0	9'548'445
OUT	RA	OC	OUT	OUT	2031	0	187'792	-13'709	0	0	9'722'528
OUT	RA	OC	OUT	OUT	2032	0	173'080	-12'635	0	0	9'882'973
OUT	RA	OC	OUT	OUT	2033	0	159'521	-11'645	0	0	10'030'849
OUT	RA	OC	OUT	RC20	2034	0	147'024	-10'733	0	0	10'167'140
OUT	RA	OC	OUT	OUT	2035	0	135'506	-9'892	0	0	10'292'753
OUT	RA	OC	OUT	OUT	2036	0	124'890	-9'117	0	0	10'408'526
OUT	RA	OC	OUT	OUT	2037	0	115'106	-8'403	0	0	10'515'230
OUT	RA	OC	OUT	OUT	2038	0	106'088	-7'744	0	0	10'613'574
OUT	SC	OUT	RC	OUT	2039	0	-7'960	0	-178'444	0	10'427'170
OUT	OUT	OUT	RC	RV25	2039	0	0	0	-178'444	11'204	10'446'334
OUT	OUT	OUT	DC	OUT	2039	0	0	0	-124'911	0	10'488'663
OUT	SC	OUT	OUT	OUT	2040	0	-7'336	0	0	0	10'419'834
OUT	SC	OUT	OUT	OUT	2041	0	-6'761	0	0	0	10'413'073
OUT	SC	OUT	OUT	OUT	2042	0	-6'232	0	0	0	10'406'841
OUT	SC	OUT	OUT	OUT	2043	0	-5'744	0	0	0	10'401'098
OUT	RA	OC	RC	RC30	2044	0	65'026	-4'747	-118'673	0	10'342'704
OUT	RA	OC	OUT	OUT	2045	0	59'932	-4'375	0	0	10'398'261
OUT	RA	OC	OUT	OUT	2046	0	55'237	-4'032	0	0	10'449'466
OUT	RA	OC	OUT	OUT	2047	0	50'910	-3'716	0	0	10'496'659
OUT	RA	OC	OUT	OUT	2048	0	46'921	-3'425	0	0	10'540'155
OUT	RA	OC	OUT	OUT	2049	0	43'246	-3'157	0	0	10'580'244
OUT	RA	OC	OUT	OUT	2050	0	39'858	-2'910	0	0	10'617'192
OUT	RA	OC	OUT	OUT	2051	0	36'735	-2'682	0	0	10'651'245
OUT	RA	OC	OUT	OUT	2052	0	33'857	-2'472	0	0	10'682'631
OUT	RA	OC	OUT	OUT	2053	0	31'205	-2'278	0	0	10'711'558
OUT	RA	OC	OUT	RC40	2054	0	28'760	-2'099	0	0	10'738'219
OUT	RA	OC	OUT	OUT	2055	0	26'507	-1'935	0	0	10'762'791
OUT	RA	OC	OUT	OUT	2056	0	24'431	-1'783	0	0	10'785'438
OUT	RA	OC	OUT	OUT	2057	0	22'517	-1'644	0	0	10'806'311
OUT	RA	OC	OUT	OUT	2058	0	20'753	-1'515	0	0	10'825'548
OUT	RA	OC	OUT	OUT	2059	0	19'127	-1'396	0	0	10'843'279
OUT	RA	OC	OUT	OUT	2060	0	17'628	-1'287	0	0	10'859'621
OUT	RA	OC	OUT	OUT	2061	0	16'247	-1'186	0	0	10'874'682
OUT	RA	OC	OUT	OUT	2062	0	14'975	-1'093	0	0	10'888'563
OUT	RA	OC	OUT	OUT	2063	0	13'801	-1'008	0	0	10'901'357
OUT	OUT	OUT	DC	OUT	2064	0	0	0	-16'250	0	10'885'107

Table B-3: Set up the spreadsheet used to calculate the net present value for several scenarios and input parameters; common barge terminal using Containerland (five scenarios, service life of the inner lake of 10 years and discount rate of 8.5%)

Whole lifecycle costs

The structures that result in the largest net present value of each alternative have the lowest whole lifecycle costs *(see Figure B-14).*

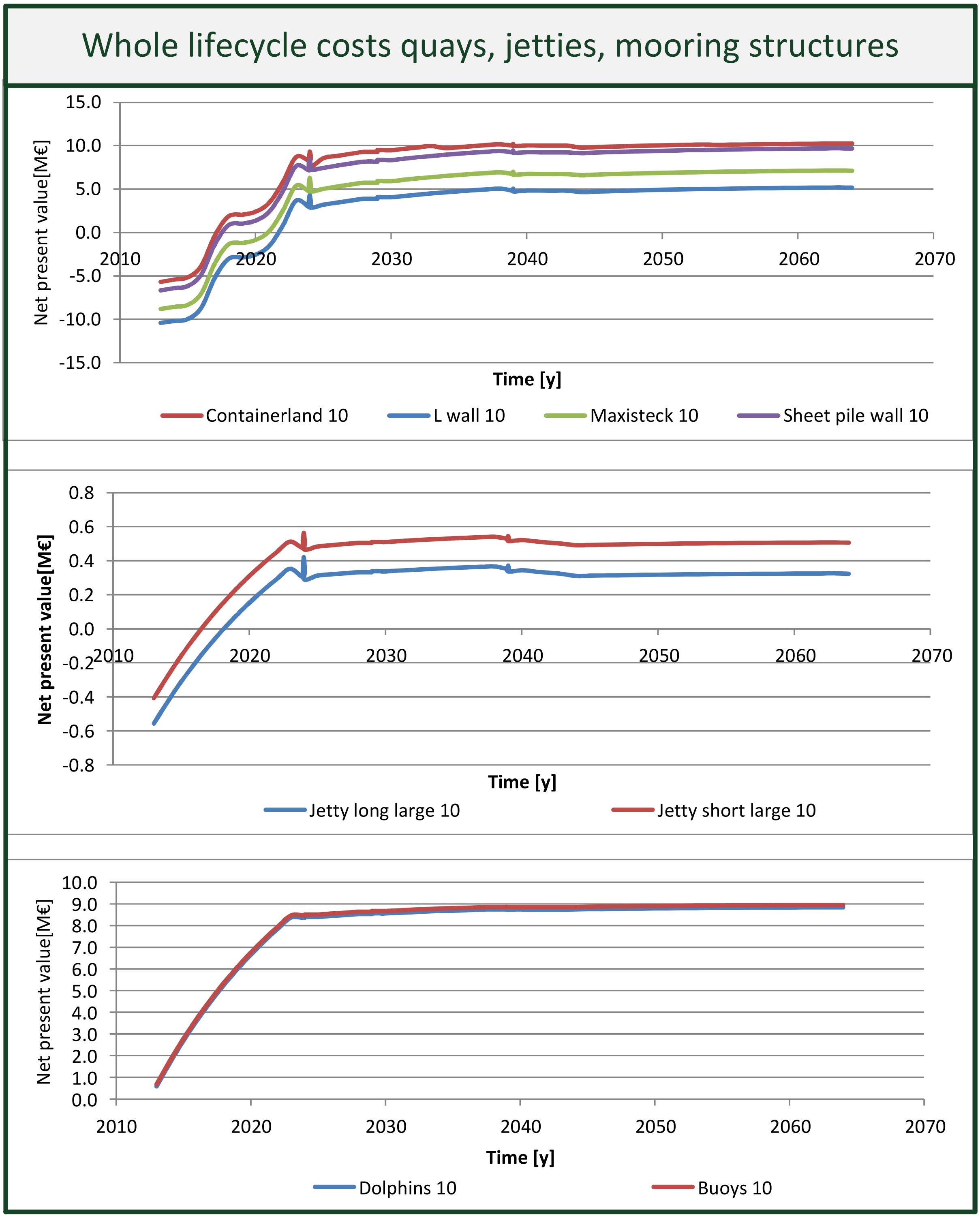


Figure B-14: Net present value of quays (common barge terminal), jetties (hotel at work) and mooring structures (liquid bulk transshipment) for a service life of the inner lake of 10 years and a discount rate of 8.5%

Rest value
An indication whether reuse-possibilities have to be considered *(see Section 7.3).*

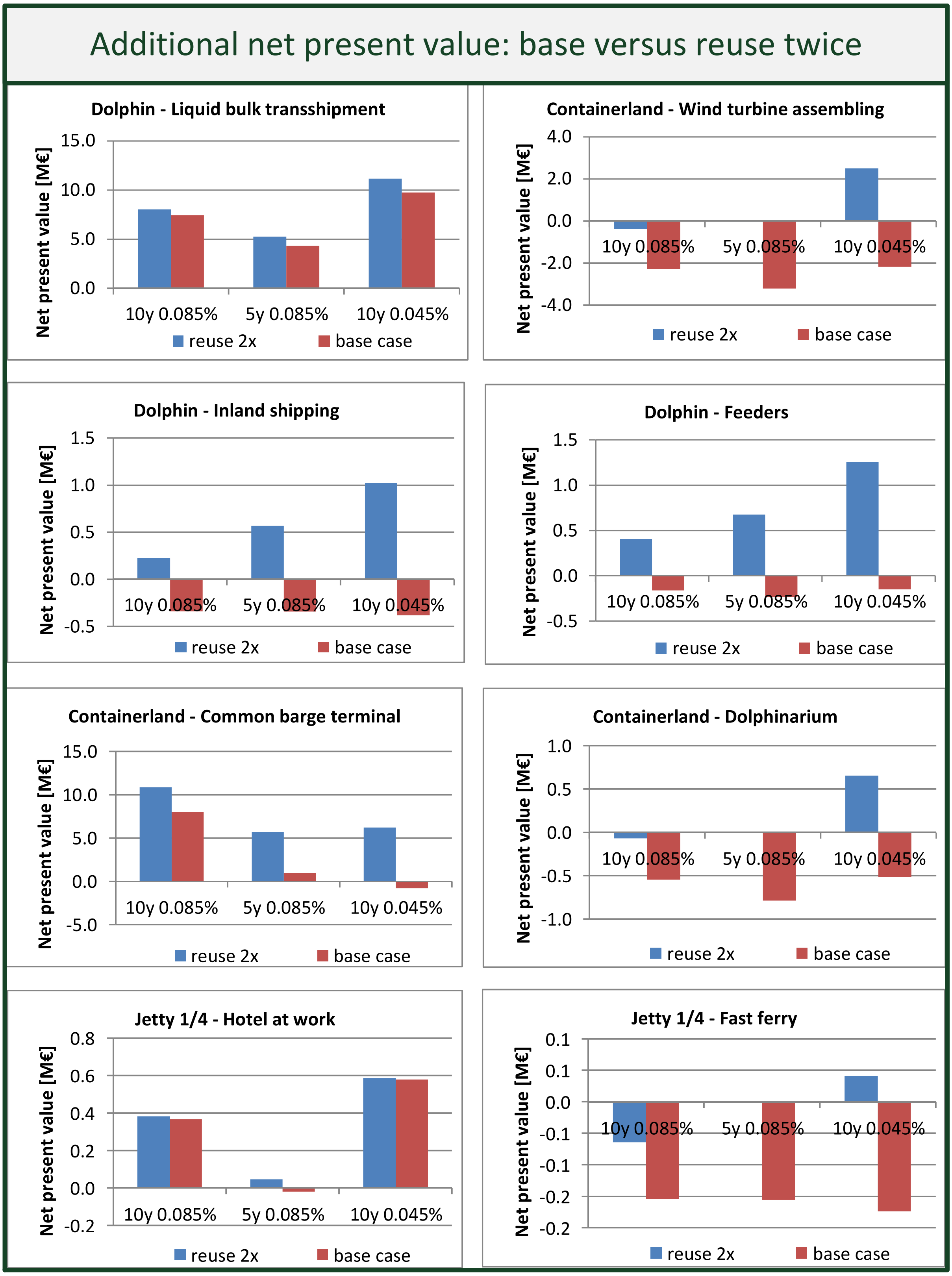


Figure B-15: Net present values base (blue, left column) and reuse twice (red, right column) for medium input parameters (service life 10 years, discount rate 8.5%), short service life (5 y) and low discount rate (4.5%)

C Common barge terminal

C.1 Additional throughput and capacity

Port of Rotterdam Authority predicts the increase in throughput with economic scenarios [53]. The throughput increases on average with 5.74% per year *(see Table C-1).* Simultaneously the effect of a low growth (3%) and global economy (9%) scenarios are included in the business case.

Average throughput increase					
Scenario	**2030 [tons]**	**2010 [tons]**	**Increase [tons]**	**Increase [tons/y**	**Increase [%/y]**
Low growth	225'000'000	135'000'000	90'000'000	4'500'000	3.33%
European trend	310'000'000	135'000'000	175'000'000	8'750'000	6.48%
Global economy	360'000'000	135'000'000	225'000'000	11'250'000	8.33%
High oil price	265'000'000	135'000'000	130'000'000	6'500'000	4.81%
Average	290'000'000	135'000'000	155'000'000	7'750'000	5.74%

Table C-1: Determination of average growth in throughput

Port of Rotterdam Authority saves by postponing the construction of a deep sea quay wall 4,309 €/m. (55,000 – 55,000/1.085) and a feeder quay 2,742 €/m (35,000 – 35,000/1.085) [42]. These parameters are multiplied with the quay length to obtain the postponed investment costs (PIC) *(see Table C-2).*

Investment costs per quay						
Terminal	**Phase**	**Quay length [m]**	**Quay type**	**IC [€]**	**Start**	**PIC [€]**
APMT MV2	1	1'100	Deep	0	2014	0
APMT MV2	1	250	Feeder	0	2014	0
APMT MV2	2	500	Deep	27'500'000	2016	18'288'749
APMT MV2	2	250	Feeder	8'750'000	2016	5'819'147
APMT MV2	3	500	Deep	27'500'000	2022	11'209'999
APMT MV2	4	700	Deep	38'500'000	2025	12'286'959
APMT MV2	4	73	Feeder	2'555'000	2025	815'407
APMT MV2	4	140	Feeder	4'900'000	2025	1'563'795
APMT MV2	4	89	Feeder	3'115'000	2025	994'127
RWG	1	1'250	Deep	0	2014	0
RWG	1	650	Feeder	0	2014	0
RWG	1	391	Feeder	0	2014	0
RWG	2	650	Deep	35'750'000	2017	21'912'787
RWG	3	96	Feeder	3'360'000	2020	1'612'396
RWG	3	130	Feeder	4'550'000	2020	2'183'453
RWG	3	206	Feeder	7'210'000	2020	3'459'932
Euromax MV2	1	600	Deep	33'000'000	2021	14'595'419
Euromax MV2	2	600	Deep	33'000'000	2022	13'451'999

Table C-2: Investment costs (IC) and postponed investment costs (PIC) per quay

The additional throughput at the deep sea quays is calculated for all phases over several years. Deep sea quay expansions can be postponed several years *(see Table C-3):*

- The maximum throughput at a terminal is calculated by multiplying the surface of the terminal with the maximum productivity (27,700 TEU/ha/y).
- The cumulative throughput adds the throughput of several phases together.
- The additional throughput is calculated by multiplying the cumulative throughput with the postponed years (P) and increase in throughput *(see Table C-1).*

Additional throughput						
P [y]	**Terminal**	**Phase**	**Parcel [ha]**	**Max. Throughput**	**Cum. Throughput**	**Add. Throughput**
1	APMT MV2	1	78	2'160'600	2'160'600	129'636
1	APMT MV2	2	30	831'000	2'991'600	179'496
1	APMT MV2	3	30	831'000	3'822'600	229'356
1	APMT MV2	4	34	941'800	4'764'400	285'864
1	RWG	1	72	1'994'400	1'994'400	119'664
1	RWG	2	54	1'495'800	3'490'200	209'412
1	RWG	3	20	554'000	4'044'200	242'652
1	Euromax MV2	1	58	1'606'600	1'606'600	96'396
1	Euromax MV2	2	27	747'900	2'354'500	141'270
2	APMT MV2	1	78	2'160'600	2'160'600	259'272
2	APMT MV2	2	30	831'000	2'991'600	358'992
2	APMT MV2	3	30	831'000	3'822'600	458'712
2	APMT MV2	4	34	941'800	4'764'400	571'728
2	RWG	1	72	1'994'400	1'994'400	239'328
2	RWG	2	54	1'495'800	3'490'200	418'824
2	RWG	3	20	554'000	4'044'200	485'304
2	Euromax MV2	1	58	1'606'600	1'606'600	192'792
2	Euromax MV2	2	27	747'900	2'354'500	282'540
3	APMT MV2	1	78	2'160'600	2'160'600	388'908
3	APMT MV2	2	30	831'000	2'991'600	538'488
3	APMT MV2	3	30	831'000	3'822'600	688'068
3	APMT MV2	4	34	941'800	4'764'400	857'592
3	RWG	1	72	1'994'400	1'994'400	358'992
3	RWG	2	54	1'495'800	3'490'200	628'236
3	RWG	3	20	554'000	4'044'200	727'956
3	Euromax MV2	1	58	1'606'600	1'606'600	289'188
3	Euromax MV2	2	27	747'900	2'354'500	423'810

Table C-3: Determination of additional throughput (in TEU/y)

The additional capacity (AC) is calculated by multiplying the throughput of the inland vessels (TP) with the relative quay efficiency *(see Table C-4):*

- The throughput of inland vessels that transship at most 25 and 50 TEU is determined (TP) with modal split (39%) and a percentage of the cumulative throughput (3% <25TEU, 9% <50TEU).
- The call size factor indicates the increase in of the cumulative throughput percentage. 100, 150 and 200% are assumed.
- The relative quay efficiency indicates how much containers can be handled additionally at the deep sea quay by handling 1 TEU at the common barge terminal. A deep sea terminal operator can transship 3.62 TEU by handling <25TEU call size and 2.62 TEU by handling <50TEU call size at a common barge terminal.

Additional capacity							
CS factor	**P [y]**	**Terminal**	**Phase**	**Throughput 25**	**Throughput 50**	**Additional cap**	**Additional cap**
100.00%	1	APMT MV2	1	26'796	53'592	96'979	140'322
100.00%	1	APMT MV2	2	37'102	74'204	134'279	194'292
100.00%	1	APMT MV2	3	47'408	94'816	171'579	248'262
100.00%	1	APMT MV2	4	59'088	118'176	213'852	309'428
100.00%	1	RWG	1	24'735	49'469	89'519	129'528
100.00%	1	RWG	2	43'285	86'571	156'659	226'674
100.00%	1	RWG	3	50'156	100'312	181'526	262'654
100.00%	1	Euromax MV2	1	19'925	39'850	72'113	104'342
100.00%	1	Euromax MV2	2	29'201	58'401	105'683	152'915
100.00%	2	APMT MV2	1	28'313	56'625	102'469	148'265
100.00%	2	APMT MV2	2	39'202	78'404	141'880	205'290
100.00%	2	APMT MV2	3	50'091	100'183	181'291	262'315
100.00%	2	APMT MV2	4	62'433	124'865	225'957	326'943
100.00%	2	RWG	1	26'135	52'269	94'587	136'860
100.00%	2	RWG	2	45'736	91'471	165'527	239'505
100.00%	2	RWG	3	52'995	105'990	191'801	277'522
100.00%	2	Euromax MV2	1	21'053	42'106	76'195	110'248
100.00%	2	Euromax MV2	2	30'853	61'707	111'665	161'571
100.00%	3	APMT MV2	1	29'829	59'658	107'958	156'208
100.00%	3	APMT MV2	2	41'302	82'604	149'481	216'288
100.00%	3	APMT MV2	3	52'775	105'550	191'003	276'368
100.00%	3	APMT MV2	4	65'777	131'555	238'062	344'458
100.00%	3	RWG	1	27'535	55'069	99'654	144'192
100.00%	3	RWG	2	48'186	96'371	174'394	252'336
100.00%	3	RWG	3	55'834	111'668	202'076	292'389
100.00%	3	Euromax MV2	1	22'181	44'361	80'277	116'154
100.00%	3	Euromax MV2	2	32'506	65'012	117'647	170'226

Table C-4: Throughput to the common barge terminal (CBT) and additional throughput at the deep sea quay per phase

C.2 Business cases

General

The usage of a common barge terminal on Maasvlakte 2 has consequences for Port of Rotterdam Authority, the terminal operators and inland vessels. This research only takes some effects into account *(see Table C-5):*

Effects CBT in business case			
Party	**Consequences of a common barge terminal on Maasvlakte 2**	**Effect**	**In BC?**
Port of Rotterdam Authority	Cost savings postponing investment deep sea quays	+	Yes
	Loss contract income postponing terminal expansions	-	Yes
	Contract income common barge terminal	+	Yes
	Investments inland quay common barge terminal	-	Yes
	Cost savings postponing investment empty storage	+	No
	Change modal split in favor of inland shipping	+	No
Terminal operator	Cost savings postponing investment terminal equipment	+	No
	Operation at optimal throughput: lower costs (labour, energy)	+	No
	Pay only option on expansion, instead of rent	+	No
	Additional transport fee (shuttles)	-	No
In-land shipp	Cost savings due to shorter sailing distances	+	No
	Shorter delivery times (no more hopping, faster transshipment)	+	No
Common barge terminal	Investment terminal equipment	-	Yes
	Operational costs terminal (handling, labour, energy)	-	Yes
	Pay additional transport to deep sea quays and back	-	Yes
	Additional transport fee (shuttles from CBT to terminal and back)	+	Yes

Table C-5: Overview of all advantages and disadvantages of the common barge terminal to the stakeholders, only some effects are taken into account in this research

Port of Rotterdam Authority
The net present cost savings are calculated by adding all cost savings (CS) and loss of rent (LCI) of each postponed quay expansion at Maasvlakte 2 for three discount rates (4.5, 8.5, 12.5%) together *(see Table C-6):*

Cost savings versus loss contract income									
r	P [y]	Terminal	Phase	Start	IC [M€]	CBT start	PIC [M€]	Cost savings	Loss in rent
4.50%	1	APMT MV2	1	2014	0.0	2015	0.0	0.0	0.0
4.50%	1	APMT MV2	2	2016	29.1	2017	27.8	1.3	0.9
4.50%	1	APMT MV2	3	2022	16.9	2023	16.2	0.7	0.7
4.50%	1	APMT MV2	4	2025	26.5	2026	25.4	1.1	0.7
4.50%	1	RWG	1	2014	0.0	2015	0.0	0.0	0.0
4.50%	1	RWG	2	2017	27.5	2018	26.3	1.2	1.6
4.50%	1	RWG	3	2020	10.2	2021	9.7	0.4	0.5
4.50%	1	Euromax MV2	1	2021	21.2	2022	20.3	0.9	1.5
4.50%	1	Euromax MV2	2	2022	20.3	2023	19.5	0.9	0.7
4.50%	2	APMT MV2	1	2014	0.0	2016	0.0	0.0	0.0
4.50%	2	APMT MV2	2	2016	29.1	2018	26.6	2.5	0.9
4.50%	2	APMT MV2	3	2022	16.9	2024	15.5	1.4	0.7
4.50%	2	APMT MV2	4	2025	26.5	2027	24.3	2.2	0.7
4.50%	2	RWG	1	2014	0.0	2016	0.0	0.0	0.0
4.50%	2	RWG	2	2017	27.5	2019	25.1	2.3	1.6
4.50%	2	RWG	3	2020	10.2	2022	9.3	0.9	0.5
4.50%	2	Euromax MV2	1	2021	21.2	2023	19.5	1.8	1.5
4.50%	2	Euromax MV2	2	2022	20.3	2024	18.6	1.7	0.7
4.50%	3	APMT MV2	1	2014	0.0	2017	0.0	0.0	0.0
4.50%	3	APMT MV2	2	2016	29.1	2019	25.5	3.6	0.9
4.50%	3	APMT MV2	3	2022	16.9	2025	14.8	2.1	0.7
4.50%	3	APMT MV2	4	2025	26.5	2028	23.2	3.3	0.7
4.50%	3	RWG	1	2014	0.0	2017	0.0	0.0	0.0
4.50%	3	RWG	2	2017	27.5	2020	24.1	3.4	1.6
4.50%	3	RWG	3	2020	10.2	2023	8.9	1.3	0.5
4.50%	3	Euromax MV2	1	2021	21.2	2024	18.6	2.6	1.5
4.50%	3	Euromax MV2	2	2022	20.3	2025	17.8	2.5	0.7

Table C-6: Determination net costs savings; discount rate (r), investment costs (IC), postponed investment costs (PIC), cost savings [M€] and losses in rent [M€]

The net costs savings differ per discount rate, small call size factor and throughput increase. Larger net cost savings are obtained for *(see Figure C-1):*

- Larger discount rates: The value of future costs and revenues is lower. The difference between present and future costs and revenues is larger.
- Larger small call size factors: More space and time available at the deep sea quays.
- Smaller throughput increase percentages: Doubling throughput percentages means an additional throughput that is twice as large, but an additional capacity that is only several percentages larger.

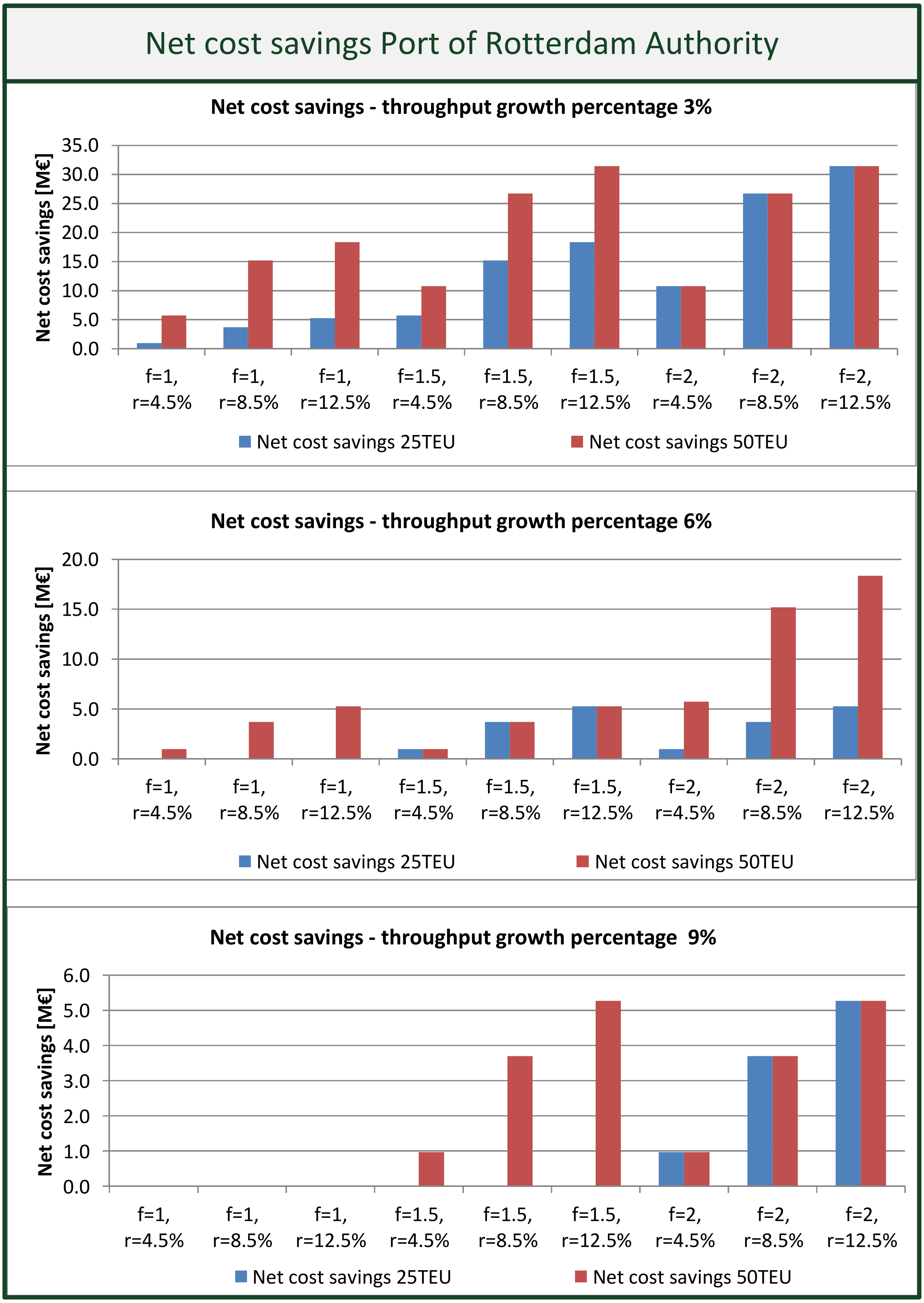


Figure C-1: Net cost savings for different discount rates (r), small call size factors (f) and throughput increase percentages for a common barge terminal that handles <25TEU call size vessels (blue, left column) or <50TEU call size vessels (red, right column)

Common barge terminal operator

The common barge terminal operator has to invest in terminal equipment (about 20 M€ [70]), pay handling and additional transport costs (about 70 €/TEU [55]) and receive an additional transport fee from the deep sea terminal operators (estimated at 85 €/TEU) *(see Figure C-2):*

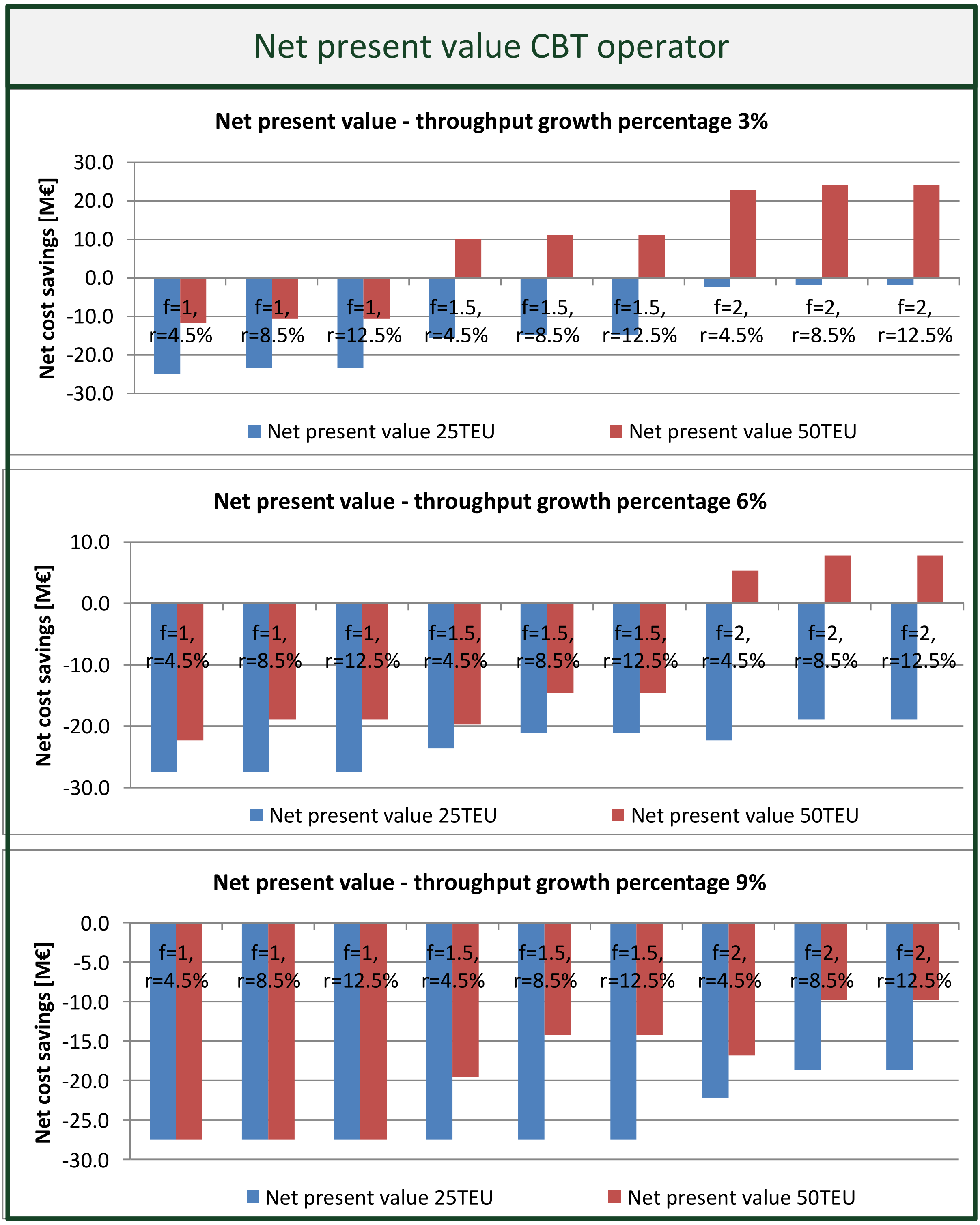


Figure C-2: Net present value for the CBT operator for different discount rates (r), small call size factors (f) and throughput increase percentages for a CBT that handles <25TEU call size vessels (blue, left column) or <50TEU call size vessels (red, right column)

The maximum throughput can be used to determine the size of the common barge terminal. A quay length of 300 m is chosen [55]. The maximum throughput depends in the first place on the small call size percentage *(see Figure C-3):*

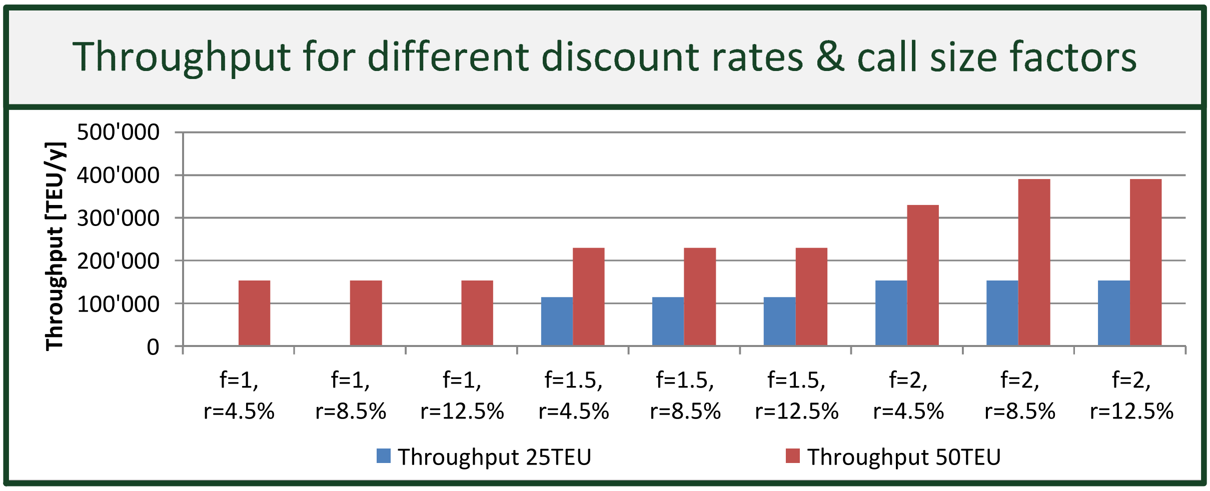


Figure C-3: Maximum throughput at the common barge terminal for different input values

The throughput originates from different terminals. An analysis of the throughput pattern enables to adjust deep sea quay expansion to the common barge terminal capacity. Different throughputs coincide once for a <25TEU call size common barge terminal *(see Figure C-4):*

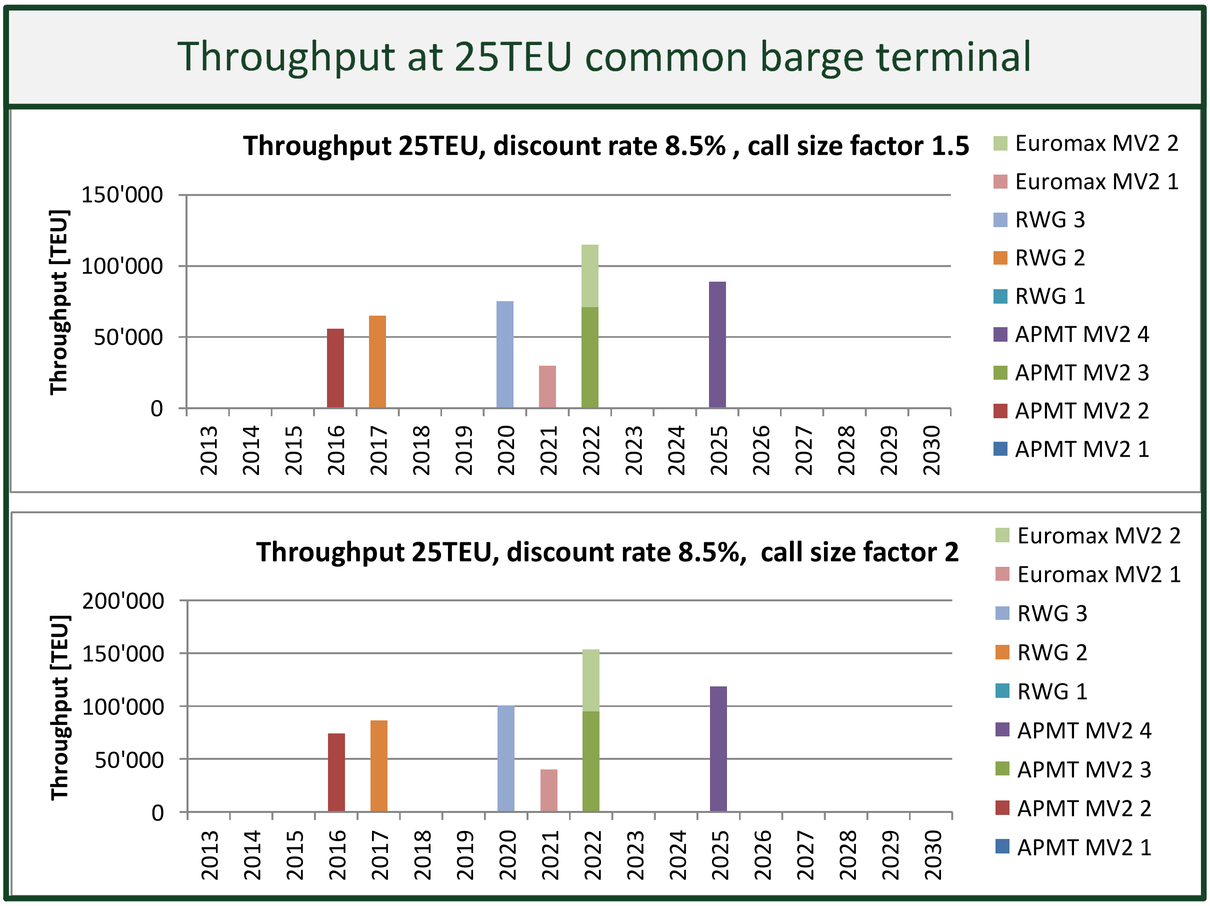


Figure C-4: Throughput at the common barge terminal per terminal phase *(see Figure 6.2)*

For a <50TEU call size common barge terminal different throughputs coincide more than once *(see Figure C-5):*

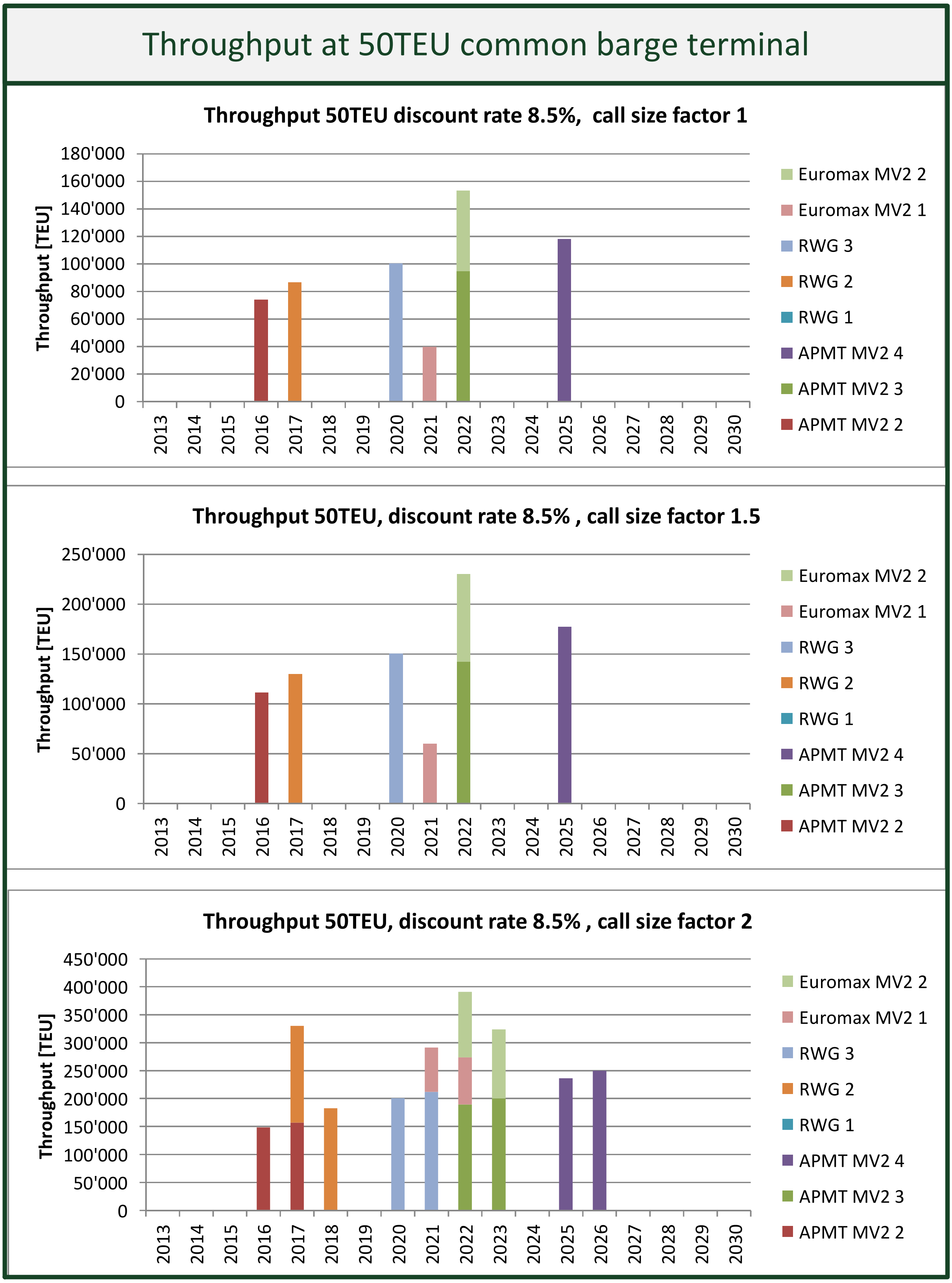


Figure C-5: Throughput at the common barge terminal per terminal phase per year