



# Port of the future

## Exploratory study





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1220137-000



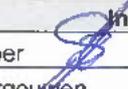
**Title**  
Port of the future

<b>Project</b>	<b>Reference</b>	<b>Pages</b>
1220137-000	1220137-000-ZKS-0005	74

**Keywords**  
Sustainable, port development, ecosystem service, morphology, design, governance.

**Summary**  
The growing number of port development projects recognises the need to shift economies and social structures towards more sustainable models. The development of a new or extended port layout requires adequate attention to a number of aspects that guarantee both sustainable port growth and a healthy ecosystem functioning. There is a need for innovative solutions for port development which are in harmony with the ecosystem and which are robust or adaptable under change. In this study we discuss the no-impact port development concept in co-creation with principles from morphology, infrastructure engineering, ecological and socio-economic perspectives. For the no-impact port development, multidisciplinary criteria have been specified, based on functions of the coastal ecosystems. This report also considers port governance models and elements of financing 'no impact ports'.

**References**  
Deltares, Green Port development, Port of the Future.

Version	Date	Authors	Initials	Review	Initials	Approval	Initials
	April 2015	Cor Schipper		Victor Langenberg		Frank Hoozemans	
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# 1 Introduction

## 1.1 Worldwide context

A growing consensus recognises the need to shift economies and social structures towards more sustainable models. The rising tide of political interest in combining 'growth' with 'green' is an explicit item on the agenda of key countries, particularly in East Asia, Africa and the European Union, where sustainable strategies are at the heart of its blueprint for competitiveness (World Bank, 2012a). This concept of Green Growth enables policy makers and companies to identify successful strategies they can adopt, and pitfalls they can avoid, in drafting and implementing green growth policies. Shipping container and cargo traffic rates are important measures of economic growth. During the last decades, world container traffic grew substantially, reflecting the expansion of world trade and rapid economic growth in the developing world and further increase in wealth worldwide (Port of Rotterdam, 2008; Port of Hamburg, 2012a; Lam and Notteboom, 2012). Recently, in line with the concept of the green growth, sustainable port initiatives have been developed by combining sustainable economic growth with environmental measures for an improved cost-benefit strategy.

## 1.2 What is the problem?

On-going trends such as global trade growth, increasing vessel sizes, and the need to modernize port facilities, are driving urgent investments in ports (OECD 2012, PIANC 2014a). Not keeping up will mean loss of trade and competitive position. The main motivation for this research is to find opportunities to facilitate co-creation in sustainable or green port development and implementation of this kind of ports in order to turn traditional port development into green initiatives. However, activities related to port development negatively impact our city port, river- and delta ecosystems.. Port projects too are confronted by a growing scarcity of prime locations, increasing environmental constraints, limited space for sustainable expansion, and uncertain impacts of climate and technological change. Clearly, there is a need for innovative solutions for sustainable port development which are in harmony with the ecosystem and which are robust or adaptable under change. Nevertheless, in general, ports that do not aim for sustainability and that impact the environment could act as a hindrance to environmental and sustainable trade. They will continue to do so unless port capacity and efficiency can be shown to benefit more from sustainable port development than from traditional approaches.

## 1.3 The traditional port

Branch (1986, p.1) defines a port as follows: "(A port is) [...] a terminal and an area within which ships are loaded and/or discharged of cargo [...] Usually, it has an interface with other forms of transport and in doing so provides connecting services." Jansson and Shneerson (1982, p10) envisaged this as a chain of operations as depicted below. The traditional seaports were built at a time when there was an exclusive focus on local trade, with often a characterized polluted industry, deficient transport, and little interest in public health, citizen welfare and no awareness for environmental issues. Early in the 20th century, the ports were characterized by high emissions as by contaminated emerging compounds emitted by local industry, vulnerable to poor water quality and air pollution. Ports were concrete and steel ruled, and squeezed into the growing cities or cities grew out of wherever ports were put down. Moreover, during the industrial revolution ports created jobs attracting many people who settled in close vicinity of the port. (Figure 1.1).



Figure 1.1 Artist impression of a 'traditional' port characterized by polluted industry, deficient transport, and little interest in public health, citizen welfare and no awareness of environmental issues. (Deltares, 2015; drawer Oomen).

Connections with the hinterland were not designed for rapid economic growth and so, with growing port volumes, the good flows were difficult to manage and there was a need to develop intelligent traffic management solutions (Port of Hamburg, 2012b). Ports could not cope with the rapid rise in international transport, since the unloading of cargo was done by hand and spurring the manufacture of small ships (Figure 1.2). Heavy industries and harbour activities created in general a negative impact on the ecosystem (De Boer et al., 2001; Bolam et al., 2006; Aloui-Bejaoui and Afli, 2012). The historic, inefficient cargo transfer changed in the last decades to container transport, which initiated a significant increase in port development and economic growth.

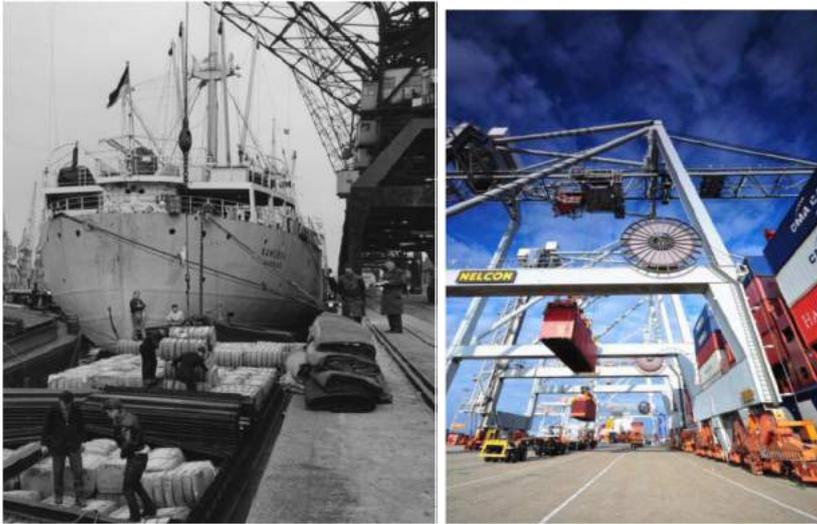


Figure 1.2. Growth in port development changing polluted into healthy ecosystems and poor into beneficial economic growth with (left) Rotterdam in 1963 (Rotterdam city archives) and (right) Rotterdam in 2013 (ECT 2013).

Ports became vital for trade and a nation's economy, but the activities associated with traditional port development, such as land reclamation, dredging and large-scale construction, negatively affected the local and regional ecosystems. Of particular concern for expanding ports is the increased truck traffic that will result from larger ports, bigger ships, and a higher volume of containers. Nowadays, there is a need to develop ports that are more in harmony with or contribute to safeguarding or restoring ecosystem functioning. Such approaches require a successful balance between logistical, morphological, economic, ecological and social processes.

The variety in ports is large; they can range from a small sheltered patch of sea protecting fishermen to moor their boats to a large industrial complex like Rotterdam or Shanghai, that include hundreds of companies, roads, railway lines, distribution centres, refineries and other industrial and manufacturing activity (Haralambides 2002). The shared characteristic is that the main purpose of a port is to enable the transfer of goods from sea to shore and vice versa, and is as such an interface between sea and land (Haralambides 2002). To enable this, a port needs to provide the following functionalities: (a) the ability for vessels to reach the port and the mooring berths within the port (depends on depth, margin to manoeuvre, wave motion); (b) the ability to moor (depends on the type of traffic, wave motion, margin to manoeuvre within the harbour area); (c) transshipment of goods and products and (d) connection to the hinterland. A port supplies a service on a market where there is demand for this specific type of "moving goods". In geographic terms, the market which a port is serving is its hinterland. The hinterland spans the range of origins and destinations which demand transport services from the particular port. A distinction can be made between captive and contestable hinterlands. De Langen (2007) clearly describes this distinction: "All regions where one port has a substantial competitive advantage because of lower generalized transport costs to these regions belong to the captive hinterland of this port. Consequently, this port handles the vast majority of all cargoes to/from these regions. Contestable hinterlands, on the other hand, consist of all those regions where there is no single port with a clear cost advantage over competing ports." As a consequence, ports compete over market share in the contestable hinterland.

#### 1.4 Towards an ecosystem-based port development, the no-impact port

The sustainable or green port development consists of optimizing the economic, environmental and social benefits of ports, including city ports with connecting waterways, and hinterland connections, surrounding cities and adjacent coastlines. The ecosystem

functioning delivers or sustains a service, for example, the navigability of channels and harbours. Several international organisations focus on the development of a sustainable infrastructure design concept in co-creation with principles from engineering, ecological and socio-economic perspectives. The awareness of sustainability in combination with green growth is rising, but the existing knowledge gap as to its incorporation into development of infrastructures is vast. As port investments are increasingly financed by the private sector (multi-national terminal operators among others), most countries rush to expand, upgrade or develop ports to receive mega vessels. The market for utilization of sustainable knowledge is worldwide. The market will consist mainly of harbours where expansion will be needed in the future and/or new innovative elements can be included in the design.

In port development we recognize that by management failure, conflict occurs between various users (port authorities, conservationists, fisheries, tourism, local communities) and between jurisdictions charged with management of the port (ministries). In part, port development is due to negligence or a lack of awareness since it fails to consider how multiple and cumulative uses can affect ecosystems. Several international maritime organisations, NGOs and Banks started with international sustainability initiatives, some of them focus on Green Port development (Figure 1.3) (IFC, 2012; OECD, 2012; PIANC, 2014b; Schipper, 2014). This organisation uses different definitions of sustainable port initiatives. Recent initiatives from PIANC and IAPH (International Association of Ports and Harbors) suggest to move away from the traditional approach and adopt interventions as an opportunity to create added value of Green Port development.

A definition of a sustainable or green port is one in which the port authority and port users pro-actively and responsibly develop and operate, based on an economic green growth strategy (PIANC, 2014b). PIANC has emphasised with strength the need to develop a Working with Nature philosophy of designing and operating, waterborne infrastructure and stakeholder participation. Starting point is a long-term vision on the area in which it is located and from its privileged position within the logistic chain, thus assuring development that anticipates the needs of future generations, for their own benefit and the prosperity of the region that it serves (PIANC, 2014b).

In this report, we use the approach of ecosystem-based management (EBM) (UNEP, 2011) that aims to restore and protect the health, function and resilience of entire ecosystems for the benefit of all organisms. In doing so, we try to gain insight into the driving factors behind realising a **'NO-IMPACT' port development**: a port that has no negative impact on the ecosystem and recognizes ecological systems as a mix of elements that interact with each other in oceans and coast areas. The no-impact port is an approach that goes beyond examining sustainable initiatives issues or ecosystem functions in isolation. In EMB, the no-impact port, the sustainable port operation, the associated human population and economic/social systems are seen as integral parts of the ecosystem. EBM recognizes that our welfare and the health of the environment are linked. Most importantly, ecosystem-based management is concerned with the processes of change within living systems and sustaining the services that healthy ecosystems produce. Summarized; the no-impact port development is based on the EBM concept, designed and executed as an adaptive, learning-based process that applies the principles of the scientific method to the processes of management.

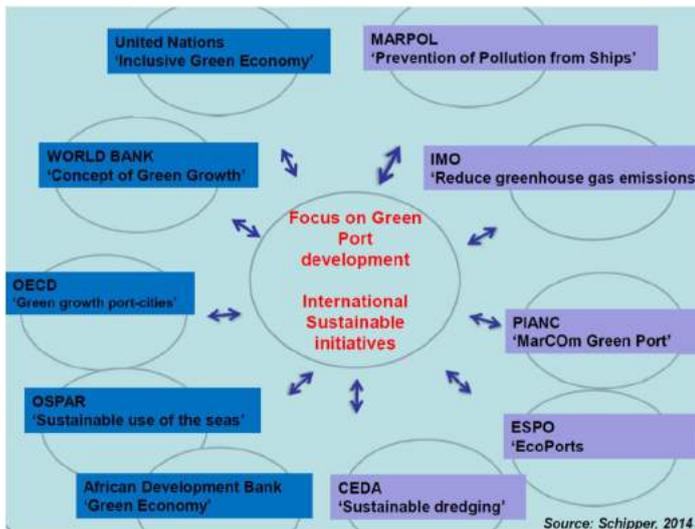


Figure 1.3 International maritime organisations (purple colour), NGOs and Banks (Blue colour) that started with sustainability initiatives such as the green growth concept (World Bank, UN, AFD).

## 1.5 Aim of this study

The aim of this Ports of the Future study, is to achieve a long term sustainable port or more opportunistic, the no-impact port development programme as an integral and interactive initiative where knowledge on this topic is developed to balance economic growth and welfare in combination with healthy ecosystems. The challenge is to find out whether a no-impact port is achievable, and under which boundary conditions. This study was commissioned by the World Wide Fund for Nature (WWF) and the Dutch Ministry of Foreign Affairs (DG-IS/DG-DIO).

The development of a new or extended port layout requires adequate attention to a number of aspects that guarantee both a healthy ecosystem functioning, as sustainable port growth. Given the economic importance of port projects and the global demand for sustainability these projects need multi annual investment. In fact, a paradigm shift is required in the approach to port development programmes whereby the emphasis lays on the functioning of a healthy ecosystem and reconciling divergent sustainable values in the future.

In this exploratory Port of the Future study, the focus will be on:

- A. Impact of port development on the ecosystem and biodiversity.
- B. Influence of the impacts of port development on the ecosystem affecting the port exploitation itself.
- C. The financing aspects of no-impact ports: what is needed to develop a sound business case?
- D. Application of optimal insight into future planning and no-impact port development.

## 1.6 Reading guide

Chapter 1 presents the aim and problems to achieve a long term sustainable port development programme as an integral initiative to avoid ecosystem damaging. In chapter 2, the function of the coastal and estuarine ecosystems and impacts of ports is presented.

In Chapter 3, the assessment of the port is discussed on the basis of the role of the geographical location, the morphology, and potential impacts of climate change impacts.

In Chapter 4, the governance criteria are discussed on the basis of the decision-making process. In Chapter 5, socio-economic rationale and finance of port development are discussed. In Chapter 6, the main factors of port development to achieve a no-impact port are discussed. Overall conclusions of the report are summarized in chapter 7.

## 2 Influence of port development and pressures on the coastal and estuarine ecosystem.

### 2.1 Functions of the coastal marine ecosystem

Coastal ecosystems are diverse throughout the world and are shaped by their environmental conditions (Burke et al., 2001). These environmental conditions set the boundaries for ecosystem development and functioning. These environmental conditions can be divided into three categories morphology, chemistry and biology, which are interrelated and can be described based on different components (Figure 2.1). These components need to be taken into account in order to determine where potential impacts will have their effects. Different distinctions of coastal ecosystems can be made based on environmental conditions. A number of examples of coastal ecosystems are coral reefs, estuaries, rocky shores, mangrove forests, soft sediments and sea grass meadows.

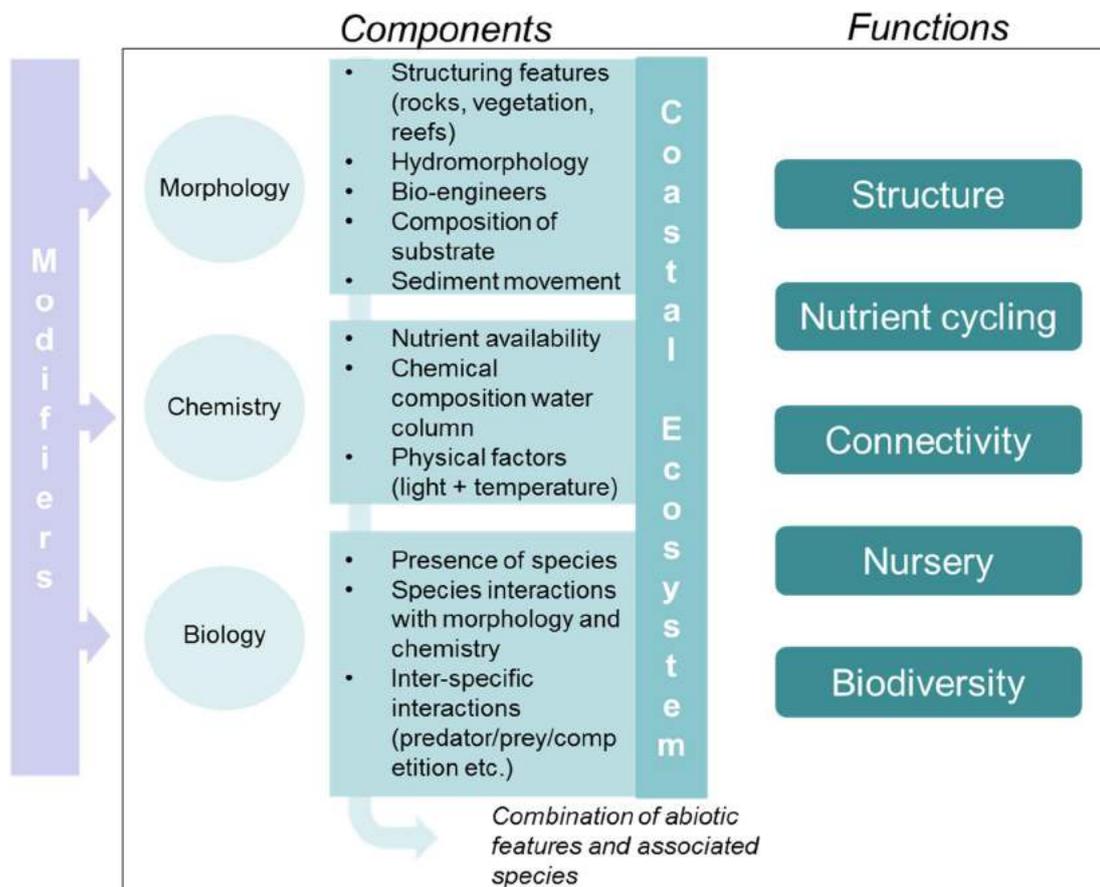


Figure 2.1 Environmental conditions set the boundaries to ecosystems with different functions. Modifications to environmental conditions can result in to changes in ecosystem functioning (Based on table by NatureServe, 2015).

Coastal ecosystems can provide many different functions that intertwine and reinforce each other, thus a balanced system is optimal and necessary. Proper functioning of the coastal ecosystem can in turn deliver a number of services such as shoreline stabilization, water quality, food production, biodiversity and climate regulation that are important for people either directly (e.g. food) or indirectly (e.g. climate regulation) (McVittie & Hussain, 2013).

The availability of these ecosystem services depend on the proper functioning of coastal ecosystems. This paragraph will provide a short overview of a number of functions associated with the coastal ecosystem (Figure 2.2). The description of these functions will give an idea on the importance of a balanced system for the availability of ecosystem services for human benefit and for the intrinsic value of nature.

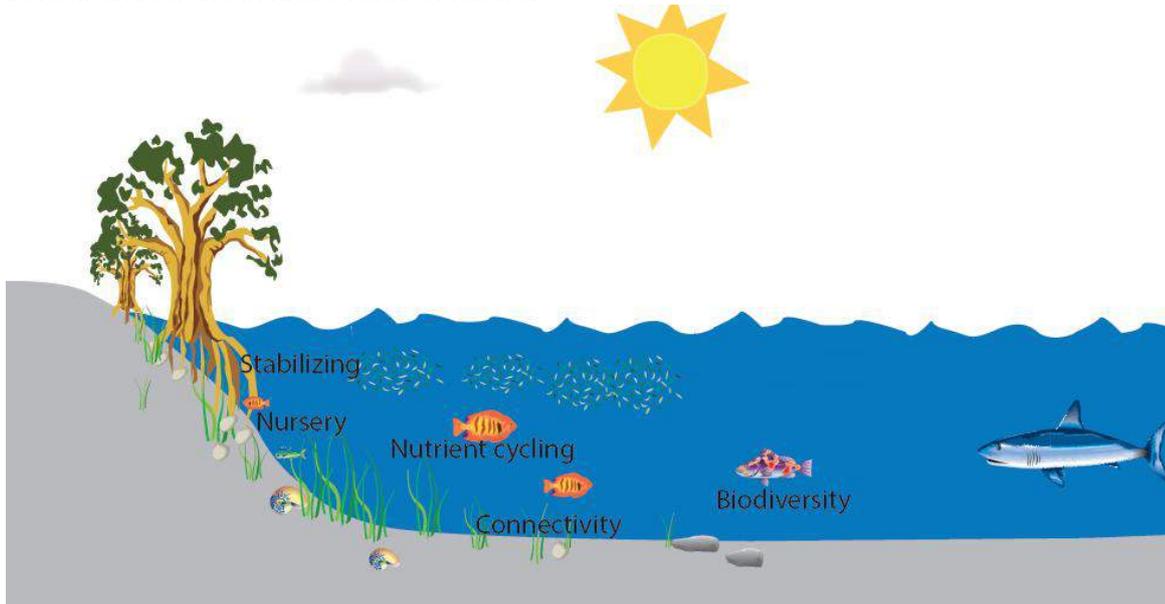


Figure 2.2 Functions of the coastal ecosystem (Deltares, 2015).

## 2.1.1 Stability

The physical environment of the coast sets the first boundaries of a coastal ecosystem. It largely determines the environmental conditions that are crucial for development and functioning of habitats. Biota of the coastal ecosystem can further affect the morphology of the coastal system since some organisms such as bivalves are able to create structures that stabilize soft sediments or attach to hard substrate such as coral reefs (Thrush & Dayton, 2002). Seagrasses of intertidal and subtidal areas are able to trap sediment, resulting in an increased stability of sandbanks and sediments (Brown, 2001) and mangrove forests are known for their ability to assure coastal stabilisation and protect the shoreline (Lee et al., 2014). A more complex and structured seafloor can have an influence on the predation of juvenile fish and can increase their rate of survival (Thrush & Dayton, 2002). These stabilizing structures can deliver benefits for people due to their positive effect on shoreline stability as well since they are often able to dissipate considerable wave energy (Marsooli & Wu, 2014) (, shores with oyster beds, coral reefs, mangroves).

## 2.1.2 Nutrient cycling and storage

Coastal ecosystems know high levels of primary production due favourable conditions of light and nutrient availability due to upwelling processes and local (in the estuary) riverine inputs and run-off. These conditions favour primary production, which is performed by different organisms in the coastal ecosystem ranging from phytoplankton and seagrasses to mangrove trees. This provides food for secondary production and eventually organic nutrients sink as detritus to the seafloor where they are processed by the benthic detritivores and bacterial community. The benthic community includes a number of different suspension feeders that are capable to remove up to 90% of the suspended matter and eject it as faecal pellets and pseudofaeces on the seafloor. Filter feeding the water column results in an increase of water quality. In addition the benthic community is known to sequester contaminants (Thrush & Dayton, 2002). Vegetation of the coastal area is often also able to trap sediment (Brown,

2001) resulting in a decrease of turbidity of the water column and making light available for primary production. Presence of favourable coastal conditions results in the cycling of these nutrients making coastal ecosystems highly productive. Primary production in the coastal system can account for significant amounts of carbon uptake and storage (Figure 2.3), for example in mangrove forests (Lee et al., 2014).

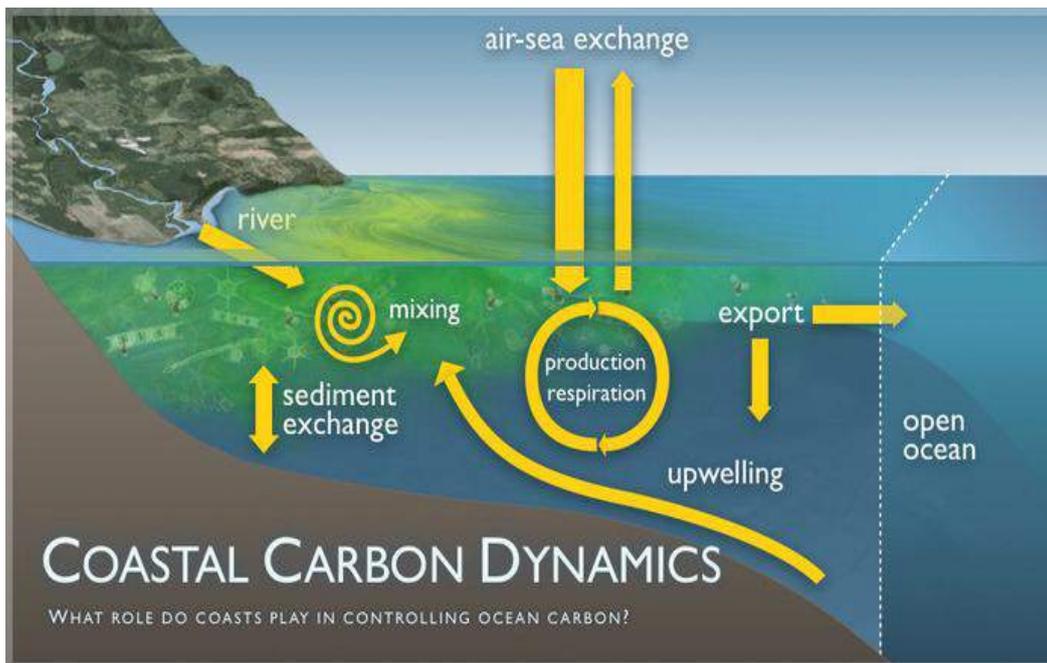


Figure 2.3 Example of nutrient cycling: carbon dynamics of the coastal ecosystem (NOAA).

### 2.1.3 Nurseries and shelter

High productivity and structuring functions of coastal ecosystems create favourable conditions with ample food availability and shelter for larval phases (Thrush & Dayton, 2002). Nurseries are coastal and often estuarine areas where fish larvae move into and grow until they move further off-shore (Beck et al., 2001). Some of the indicators that have been mentioned to determine the quality of a nursery depend on larval supply, predation, food availability, water depth, and tidal regime (Beck et al., 2001). Especially vegetation of coastal and estuarine ecosystems (e.g. mangroves, seagrass meadows) is known for its role as a nursery (Lee et al., 2014) with warmer waters in estuaries (Vinagre et al., 2012). Coral reefs are also known to provide a nursery function for many fish species (Nagelkerken et al., 2000). The function of a nursery has a direct effect on recruitment of fish species and therefore it affects both biodiversity and food availability for higher trophic levels including food for humans.

### 2.1.4 Connectivity

Ecological connectivity is often described as the degree to which the landscape facilitates dispersal between habitats, but it can also relate to broader areas such as nutrient flows (Sheaves, 2009). There are several reasons why connectivity is an important function of the coastal ecosystem. In the marine ecosystem there is a constant dispersal of species between habitats: spawning, migrating eggs and larvae, gametes, seeds, dispersal towards and from feeding grounds and dispersal or recruitment of juveniles towards adult habitats (Sheaves, 2009). Furthermore, translocation of nutrients due to moving between habitats is also related to connectivity (Sheaves, 2009). In order for connectivity to be high for a large range of species, habitat fragmentation should be prevented. Different habitats are required for

different phases in life (life history) and to access these habitats there needs to be a certain degree of connectivity between these habitats.

#### 2.1.5 Biodiversity

There are several reasons why biodiversity is high in coastal ecosystems. First of all, the relatively shallow nature of coastal systems promotes light availability for primary production and somewhat higher temperatures, like in the North Sea. Also the coasts represent land-water interface so fresh meets salt (in the estuary), land meets water. This mosaic of different biotopes creates a situation that's ideal for diverse flora and fauna. Second, nutrient levels are generally higher along the coast due to upwelling processes, anthropogenic inputs and riverine input (Ludwig et al., 2009). This generates optimal circumstances for primary production and with sufficient light it creates a high productivity in coastal ecosystems. Furthermore, different plants and the benthic community of this shallow zone can provide shelter and create different niches for different species. High biodiversity can facilitate more resilience of the ecosystem. This is due to the likelihood that a more biodiverse system will harbour more species of the same functional group. When environmental conditions change due to for example human interference or climate change, chances are larger that there will be species that respond differently to these changes. This was found in kelp forests along North America, where more highly diverse systems along the West coast were more resilient than along the east coast (Hughes et al., 2006). High diversity is however not an insurance for a more resilient system, since different species in the same functional group can also respond the same to a certain pressure as is found in an overall pressure of climate change and overfishing on coral reefs (Hughes et al., 2006).

High biodiversity can also create a more diverse and complex food web with multiple interactions between different trophic levels, which is favourable for the ecosystem since some components of biodiversity affect carbon sequestration and thus are important in carbon-based climate change mitigation when afforestation, reforestation, reduced deforestation, and biofuel plantations are involved. Healthy functioning ecosystems are a prerequisite for high biodiversity; therefore negative impacts on the coastal ecosystem ought to be prevented.

## 2.2 Estuary ecosystems

The function of estuary systems is discussed separately due to its importance in the coastal ecosystem and in port development. In the overall report, the estuary system is included in the coastal ecosystem and impacts that apply specifically to the estuary will be mentioned. Port development often takes place near river mouth due to the potential for transport upstream or in the light of disclosing the hinterland and basin resources. As a result, when a port is constructed near an estuary the estuary ecosystem experiences impacts from port use and development. Estuary ecosystems differ from the overall coastal ecosystem description in their gradient from saline to fresh water when processing further into the river and in their differences with respect to high and low tide. Estuaries are very high in productivity and are very important for functions of the coastal ecosystem as described above. Since estuaries are important for marine fish due to their nursery function and migratory patterns, they are also important for the higher trophic levels to contribute to the foodweb. Furthermore, connectivity is an important aspect for estuaries since migrating fish species can rest in estuary systems to acclimate to different salinities.

### 2.3 Potential impacts of port development on the coastal ecosystem

In order to have a no-impact port, the potential impact of port development on the coastal ecosystem has been evaluated. Both construction and operation of marine ports go hand in hand with a number of potential impacts that can affect favourable environmental conditions for ecosystem functioning (Hiranandi, 2012), and as a result affect the availability of ecosystem services. In this paragraph a ecosystem-based (EBM) approach is used to describe the potential impacts of port development on the coastal ecosystem. Potential impacts of port development on the coastal ecosystem can arise from impacts on the morphological structure of the ecosystem, on the chemical components of the ecosystem and on the biological components of the ecosystem (Figure 2.1). As a result, impacts are grouped into three categories: changes in morphology, chemistry and biology. For these three categories potential impacts associated with port development are described so and their impacts on coastal ecosystems as described in scientific literature is evaluated. Due to the exploratory scope of this report not all potential impacts can be addressed in detail. More indirect impacts on morphology, chemistry and biology could be addressed in a follow up study.

### 2.4 Changes in morphology

Physical changes to the structure of the coastal ecosystem take place when a port is developed. Port development requires the construction of waterways, breakwaters and the port itself, which is described in detail in chapter 3. These changes can affect the hydromorphology of the ecosystem and as a consequence could affect ecosystem functioning. The two direct impacts on the morphology that are discussed in this paragraph are habitat loss and development and dredging. Further impacts on morphology are described in chapter 3.

#### 2.4.1 *Impact: Habitat loss and development*

When planning construction in coastal ecosystems or estuaries, an assessment of ecological functions and connectivity of the current system could provide insight in potential effects for different functions and their importance as described in 2.1. Therefore, when choosing a location and design, system knowledge is required with respect to different processes such as hydromorphology and requirements for natural habitats in the area. To this end, indicators for ecosystem functioning such as biodiversity or presence of certain key species should be assessed. Furthermore, in the planning of the port design required environmental conditions for ecosystem functions should be taken into account.

Morphological characteristics that were in place before construction of the harbour can be removed or altered with the development of a port. A direct effect of the development of marine ports is the removal of habitats due to the construction of structures such as breakwaters and the port itself in a coastal ecosystem. Bulleri & Chapman (2010) state that hard infrastructure could support different epibiota; however its functioning is not equal to that of a natural rocky habitat. Construction of hard structures and a change of pristine environmental conditions will likely result in removal of a habitat that required those pristine conditions for functioning. Furthermore, removal of habitat may result in the disturbance of functions of the ecosystem. For example, removal of a habitat that functions as a nursery can result in a lower recruitment. This has a negative effect on biodiversity, balance of different trophic levels due changes in predation on lower trophic levels and food availability for higher trophic levels. In additions this could result in less fish available for human consumption. Furthermore, habitat loss can result in fragmentation of the ecosystem and can decrease connectivity.

## *Reduction of impact*

On the other hand, at locations where the functioning of the ecosystem is under pressure, a potential added value could be obtained by creating favourable circumstances for new habitats or restoration of disturbed areas. By including eco-engineering (making use of natural structures and processes) in the design of port development, habitats that provide different ecological functions and ecosystem services could be created. There have been a number of pilot studies with several engineering approaches, such as the creation of an artificial oyster reef, reusing dredged material for the creation of new habitats in port development and placement of a large sand body in front of the Dutch coast that can be repositioned by natural processes and improve water safety (de Vriend & van Koningsveld, 2012, figure 2.4). These eco-engineering should not interfere with operation of the port and therefore should be included in the design phase to find an optimal location for their function.



Figure 2.4 Artificial oyster reef - an example of Building with Nature to create new a habitat and mitigate wave height (source: EcoShape).

### 2.4.2 *Impact: Dredging*

In order to obtain and maintain the desired water depth and width of a port itself and the shipping lanes towards it, adjustments to the natural morphology by dredging or excavation activities have to take place in case the natural morphology does not meet the required design. Some areas require a more extensive dredging regime than others, based on hydromorphology, in order to assure transport routes (IADC, 2005).

Dredging results in a change in the physical structure at the dredging location, and at the disposal site. This can affect the hydro morphology of the ecosystem due to a change in the way the currents interact with the sediment and as a result could change the environmental conditions such as particle size of the sediment, chemistry and turbidity.

Dredging takes place in soft sediments and disturbing the seafloor by dredging activities will result in disturbing the important functions and structures of organisms on the seafloor. How relatively small scale disturbance effects will translate to a larger scale and what important thresholds are to losing ecological functioning is not well understood (Thrush & Dayton, 2002). Furthermore, turbidity of the water column can (temporarily) increase which directly affects light availability for primary production. This is also the case at disposal sites. Research by Bolam et al. (2006) on the effects of disposing of dredged material showed that impacts are site specific. Disposal of dredged material was disturbing to the benthic community but the size of the impact depended on case-specific details (Stronkhorst et al., 2003).

Despite unknown aspects of the impact of dredging and disposal of dredged material, it is likely that dredging activities affect ecosystem functioning on a short timescale due to loss of physical structures and bioturbation functions. Repeated dredging to maintain a waterway will therefore hamper full recovery of these functions.

#### *Reduction of impact*

It was noted that disposal of dredged material in a coastal area that was already subjected to relocation of sediment experienced less severe impacts and in some cases a beneficial response (Stronkhorst, 2003). Furthermore, it is noted that over the past 20-30 years there has been large progress in our capability to assess and limit the environmental impacts of dredging (CEDA, 2013; Kolman, 2014). Factors that determine whether there is an adverse effect are the quality of the dredged material (in terms of organic carbon, contamination and similar sediment), the amount, the frequency of disposal and the nature of the receiving environment (biological communities). Three out of four aspects can be adjusted easily to fit a more sustainable scheme: quality of disposed material, quantity and frequency. The location of disposal will depend on more subjective choices related to which communities or areas are considered have more intrinsic value than others (Bolam et al., 2006).

Over time, dredging has become more sustainable and has created several options for relocation of the sediment in such a way that functioning of the ecosystem can be improved. For example, relocation of dredged material in an optimal location creates opportunities for the development of seagrass meadows due to their capacity to trap sediment. However, as stated before dredging activities likely affect ecosystem functioning on a short timescale due to loss of physical structures and bioturbation functions. Repeated dredging to maintain a waterway will therefore likely prevent full recovery of these functions. In order to achieve sustainable port development, repeated dredging measures are therefore not an optimal situation and a location with more natural depths and less impact on the sedimentation processes is desired.

## **2.5 Changes in chemistry**

Changes in chemistry can relate to the nutrients in the water column that are used for primary production or the overall chemistry of the water column (Figure 2.1). Pollution or change of the water column can change favourable chemical conditions that are a requirement for ecosystem functioning. Since this paragraph focusses on pollution, other impacts that affect or pollute the water column have been included in this paragraph as well.

### *2.5.1 Impact: water pollution*

Ports are known to have a negative effect on water quality due to the pollution incidents with oil, grease and litter (Hiranandi, 2012). Water quality can be affected in harbours due to eutrophication due to organic discharge, sediment re-suspension, or accidental spills, the latter of which has been appointed as an important factor for water quality in ports (Grifoll, 2011; Schipper et al., 2009). In addition to water quality effects of the maritime industry, dredging activities can result in de suspension of sediments which increases the turbidity of the water column and therefore can have a negative impact on water quality as well (Pennekamp et al., 1996). Eco-friendly sand extraction tries to prevent negative impacts that result from changes in turbidity (De Vriend & Van Koningsveld, 2012).

In general, over-enrichment of nutrients results in a decrease in biodiversity in coastal ecosystems due to changes in the ecological community structure (Howarth et al, 2000). Furthermore, creating favourable high nutrient circumstances for phytoplankton can result in large (potentially harmful) algal blooms which reduce water and seafloor quality. Harmful algal blooms can result in mortality of shellfish and fish, human poisoning from eating contaminated

fish or shellfish and death of marine mammals or seabirds (Howarth et al., 2000). Seagrass and coral reefs are particularly sensitive to eutrophication (Howarth et al., 2000). Nitrogen enrichment is thought to be most harmful for coastal ecosystems and over-enrichment can eventually result in a loss of commercial fish due to degradation of the foodweb (Howarth et al., 2000).

Beside nutrients, oil spills associated with shipping have caused many negative effects on different parts of the ecosystem. After oil is spilled, it rapidly reached the sediment where it can have large effects on the diversity and abundance of the benthic community thus on biodiversity of the coastal ecosystem (Teal & Howarth, 1984).

Mitigating measures and strong legislation should try to reduce these impacts on water quality associated with port development.

### 2.5.2 *Impact: Contaminated sediment*

Sediments of ports can often get contaminated due to settling of contamination from river mounds close to the port or from maritime pollution such as grease or oil. It is well recognized that harbour sediments are often contaminated with persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), tributyltin (TBT), mineral oil and metals, which are of concern for the receiving marine systems (Stronkhorst and Van Hattum et al., 2003; Alvarez-Guerra et al., 2007; Schipper et al., 2010). Based on this variability there can be a range of effects from dredging that relate to its chemical composition. ).

The sediment-associated persistent and bioaccumulating toxic chemicals known to induce chronic sub-lethal effects are bound to the small sediment particle and transported to location far away from the original dumping site. Although dioxins in sediments are not acutely toxic, they are very persistent organic pollutants that often are present in harbours as by-products of incomplete combustion and industrial processes. Other example of toxic potencies of hazard compound in harbour sediments are tributyltin available in antifouling, what cause Irreversible damage of the reproduction of sea snails (Schipper et al., 2008).

#### *Reduction of impact*

Research on methods to determine the contamination of sediment using biomarkers has made it feasible to assess potential risks associated with contaminated sediments (Schipper et al, 2009). To minimize ecological effects of open water disposal of dredged sediments, knowledge of the presence and possible adverse effects of emerging chemicals in sediments is needed, since for all these chemicals generally no action levels exist, that would enable judgment of the safety of dredged material based on the chemical contents. This knowledge is required to make a reduction of impact possible.

### 2.5.3 *Impact: Air pollution*

The infrastructure that is associated with marine ports includes the presence of trucks, vessels, rail traffic, industrial sectors and other sources of air pollution (Bailey & Solomon, 2004). Marine transport is a large source of air pollution and European ports consider air quality as the most important environmental priority in 2013 (Maigret, 2014). Dust (particulate matter from transport activities) is another reason for reduced air quality around ports (OECD, 2011).

Air pollution of port development can be related to greenhouse gas emissions and particulate emissions. Composition of particulate emissions around ports can be very diverse, ranging from metals, ash, and different particulate matter fractions. Increase in carbon dioxide is a known factor in ocean acidification (NOAA). These effects do not only relate to the scale of the coastal ecosystem but extend to a larger scale. Ocean acidification in coastal areas could have a negative effect on different calcifying organisms such as bivalves, calcifying algae and

corals due to the chemical processes in the water column after uptake of carbon (NOAA, Figure 2.5). This however, is a very large scale process that will not be addressed in detail in this report. It will suffice to mention that emission of greenhouse gasses in ports can add up to the expected effects of ocean acidification. Therefore, reduction measures are advised in sustainable port development and should aim the transport sector due to the large source of air pollution (Maigret, 2014).

#### *Reduction of impact*

As a result of concerns about air quality, some progress has been made in the direction of more sustainable practices aimed at less air pollution such as low-sulphur diesel fuel and greener design of terminals (Bailey & Solomon, 2004). However, it is argued that a change of fuel alone might not be enough to reduce harmful emissions and further research might be necessary to address this topic (Mueller et al, 2011).

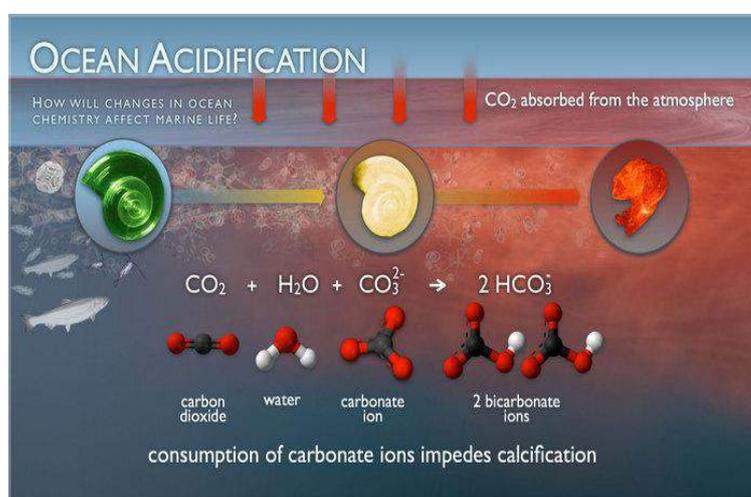


Figure 2.5 Process of ocean acidification due to rises in CO<sub>2</sub> (NOAA).

#### 2.5.4 *Impact: Noise pollution*

Traffic in ports and operation of a port comes with operation of large machinery which can cause disturbance in the form of noise disturbance and oscillations.

##### *Impact*

Anthropogenic noise pollution of marine areas has been widely addressed with respect to effects on marine mammals. Overall findings show that there can be behavioural responses, physiological stress responses and changes in communication (Rolland et al, 2012). Effects on fishes are less well reported and long term effects of noise from construction activities are unclear as of today (Popper & Hastings, 2009). However, since there is a concern about the likely effects of noise pollution on fish populations it is necessary that further research to this respect is performed. The possibly negative noise impacts should be taken into account in sustainable port design and innovations concerning sound mitigation might require additional attention.

### Reduction of impact

The OECD propose that a part of the noise would be reduced when machinery and port vehicles were switched to electrics. Furthermore, the Rotterdam Port Authority for example has the right to change the allowed noise emission levels (OECD, 2011).

## 2.6 Changes in biology

Changes in biology could relate to changes in species, intra/inter species interactions, changes in morphology and chemistry. Inter-species interactions, indirect effects in morphology and chemistry are complex processes and cannot directly be translated to impacts of port development. These aspects of biology therefore go beyond the scope of this report. The introduction of new species however, is an impact of port development that has been researched extensively and of which many incidences are known.

Port development can be associated with the introduction of alien species (Firestone & Corbett, 2006). Ballast water is a known carrier of alien species. For example, ballast water that was taken up in Japan and was released in Oregon contained 367 of plankton (Carlton & Geller, 1993). In order to maintain stability, ships take up ballast water at one port and release it at arrival. In 2004 more strict rules on the uptake and discharge and organisms in the ballast water have been adopted by the International Maritime Organization (OECD, 2011). Beside ballast water, organisms are able to attach to the hulls of ships. In order to prevent this, antifouling measures have been taken but no optimal strategy is found yet (McKenzie et al., 2011). Research on new antifouling methods is numerous; however no good solution to this has been found yet (Marechal & Hellios, 2009). Most invasions have taken place in estuarine habitats due to ballast water (Briggs, 2007). Long-term consequences of invasions have not been well documented but some invasions have been pests while others have been beneficial.

Briggs (2007) argues that as far as can be determined invasions in coastal areas have not led to decreases in biodiversity but in fact increases. Introduction of alien species introduces an extra competitive element in the present food web. It is up to the food web to incorporate or reject these species. Beside effects on biodiversity, there can also be potential pathogens in the water that could propose a threat to humans or all sorts of key species in the coastal ecosystem (International Maritime Organization). The number and frequency of introduction likely affects the potential impact of alien species in either ballast water or on ship hulls. The Panama Canal for instance knows a number of invasions that have likely occurred through either ballast water or biofouling (Ros et al., 2014).

Due to the unknown aspects and the potential risks of ballast water release, there is now more stringent legislation that tries to reduce risks by treating the water (International Maritime Organization). Improved techniques to prevent biofouling are required in addition to overcome the likelihood of introduction of invasive species.

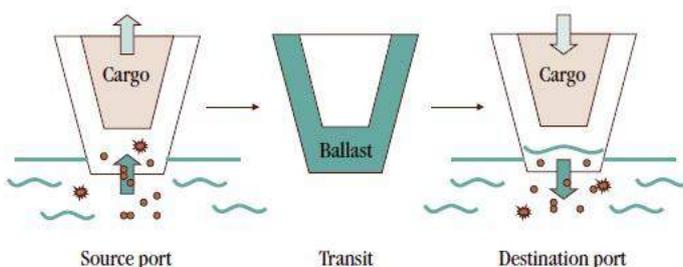


Figure 2.6 Principle of alien species in ballast water (source: [www.polarcom.gc.ca](http://www.polarcom.gc.ca)).

## 2.7 Conclusions impact port development on the ecosystem

In order to have a no-impact port, the potential impact of port development on the coastal ecosystem has been evaluated. Potential impacts of port development on the coastal ecosystem were divided into three categories of the coastal system: morphological impacts, chemical impacts (contamination) and biological impacts (alien species). With respect to chemical impacts and biological impacts, negative impacts cannot be entirely avoided. Technology has to this date not yet been optimized in such a way that biological and chemical impacts are neutral, therefore described potential effects on ecology still occur. The severity of impacts will be case specific, depending on the vulnerability of the system to different impacts and mitigating measures. Especially mitigating measures would be required to reduce impacts and possibly improve port development.

Largest risks and chances for no-impact port development lie in the morphological category of the system. Removal or disturbance of entire habitats with important functions will harm ecosystem functioning and degrade the ecosystem. A Port of the Future development should avoid this harm, where ever possible. In the next chapter, the morphological requirements and possibilities of a port are examined. The output hereof will be used in chapter 6 to determine factors that are important for an ecosystem based design of a port.

Chances lie in the morphological category as well. Taking different habitat requirements and effects of port development on the hydromorphology and chemistry into account, conditions could be used to create new habitats, improve connectivity by promoting green infrastructure and for example using dredged material to promote development of new habitats. This could have indirect effects such as mitigation of climate change or foreshore stabilization.

Whether a sustainable port could potentially have no impact on the coastal ecosystem depends on the mitigating factors of contaminants, disturbance and alien species. In order to include ecosystem functioning in port design and management and choosing of a location, the state of the current coastal ecosystem, ecological feedback and environmental requirements of physical, chemical and biotic aspects for ecosystem functioning should be assessed. Information on current biodiversity, hydrodynamics, key species and their requirements are for example necessary to have more insight in the functioning and important requirements of the relevant coastal ecosystem. Furthermore, it is required to have good monitoring of indicators for ecosystem functioning such as the abundance of key species for the system and nutrient levels (Figure 2.7).

One way to incorporate ecosystem functioning in port development is through ecosystem based management. Ecosystem based management is defined as 'an environmental management approach that recognizes the full array of interaction within an ecosystem, including humans, rather than considering single issues, species or ecosystem services in isolation' (McLeod et al., 2005). Ecosystem based management would be a means to aiming for achieving no-impact port development

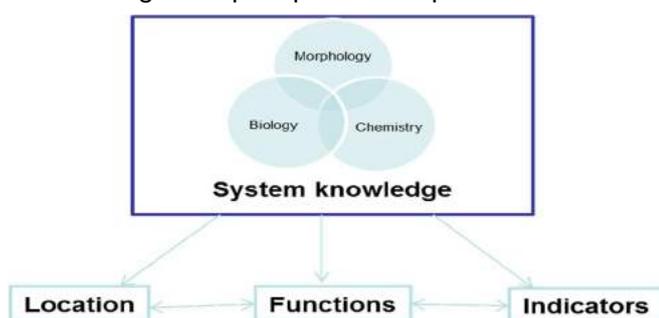


Figure 2.7 It is important to understand effects on different categories that shape the coastal ecosystem. Location, ecosystem functions and proper indicators for ecosystem health are important in determining the effects of port development.



## 3 Influence of the physical environment on ports

### 3.1 Introduction

In Chapter 2 we discussed how a port can affect its physical environment and in Chapter 5 we will discuss how a port may affect its socio-economic environment. However, a port not only affects its environment, but also the reverse occurs, that a port is affected by its environment. Hence, the location of a port is of importance for a port's design and operational management. For example, in a port located along a sandy coast dredging will be needed to obtain and maintain a minimal depth and in a port located in an area that knows many extreme storms additional protective measures might be put in place or the downtime increases (the period in which vessels cannot enter nor leave the harbour and/or use the quays for (un)loading).

In this chapter we discuss the influence of the physical environment on ports. We discuss the role of the geographical location, morphology, and potential impacts of climate change impacts. Besides physical factors we touch upon socio-economic factors that can influence a port design and operations, but also the choice for a location. The type and location of the market a port services is for example critical to a port's location and other requirements. Findings on these topics will give insight in the physical requirements of sustainable port development and will show what factors are important for a no-impact port from a physical point of view.

### 3.2 Impacts of geographical location of ports on their design and operations

In this section we discuss the role of several characteristics of geographical locations in which a port can be situated and how they may affect a ports operation.

#### *Sandy or hard, rocky coast (natural depth)*

Sandy coasts provide many degrees of freedom in designing a port. Areas can be deepened and widened to allow for large and deep-draughted vessels. Under certain circumstances ports can even be constructed on 'new' reclaimed land. However, ports located in a sandy environment will affect sedimentation patterns of the coastline, which may lead to changed sedimentation and erosion patterns along adjacent beaches. In such cases additional measures need to be taken to compensate (Mohanty et al., 2012; Hsu et al., 2007; Healy et al., 2002). When the structures interrupt a morphological pattern in which one sediment transport direction is dominant, then on one side erosion may take place and on the other side the sediments may deposit. This is because the sediment balance is interrupted. Note that even though a natural coastline does not show large changes over several years, there may still be significant sediment transports occurring, as long as they are in balance. For example, when sediment transports vary in strength and direction within a year, then the net effect per year may be small. However, when a port interrupts this process, then the gross transports become relevant, since these will accumulate in the areas adjacent to a port.

The ports themselves often function as a sink in which sediments deposit. To maintain the ports functionality and to keep it accessible dredging is then necessary. For example, Poverty Bay in New Zealand showed that the need for dredging increases significantly as a result of deepening the entrance channel (Healy et al., 2002). On the other hand, despite ports affecting the sedimentation pattern, this is usually only a local influence and does not

necessarily affect morphological processes on larger geographical scales. When the sediments are taken out of the port and deposited 'back' in the natural system, provided that the quality is sufficient (following regulations), the real impact in terms of quantity may even be marginal. Nevertheless, on a local scale impacts can be high, such as significant erosion of beaches or on larger geographical scale (Rosen, 2002).

A rocky coast is more expensive to alter, but also here ports can be constructed. A port can also be foreseen offshore to make use of the natural depths (Van der Hout et al., 2015). However, this is not always sufficient nor efficient. Additional depth might need to be created to accommodate larger vessel sizes and cargo volumes. An example of a port that uses the natural depth is the Halifax harbour in Canada. Note that many coasts consist of a mix of sand and rock and mixtures of techniques will be needed. Also here, ports and related constructions will affect sedimentation patterns.

#### *In/near estuary or closed coastline*

Ports located in or near an estuary have direct access to inland waterways, which facilitates further transportation and may strengthen the position of a port. However, a river will also bring sediment, which may lead to increased dredging inside the port. Under exceptional circumstance, the morphological activity in an estuary may be considered too high for port activities. On the other hand, depending on the water quality influenced by industrial activities in the river basin, urbanization and wastewater management schemes, the river flow inside an estuary can flush the harbour and so reduce local sedimentation and pollution, or it can increase levels of pollution as it can transport materials into the port as well (Peris-Mora et al., 2005, Vellinga, 2011). Pollutants and sediments may deposit in the port, particularly when that port has been dredged to depths beyond that of the natural system. Hence, a port needs to respond to this by dredging and/or improving on deteriorated water quality variables

#### *Presence of infrastructure*

A good connection between the market and the port is critical for a port to be competitive. Different types of transport infrastructure include road, rail and inland water ways and pipeline transport systems. Different types of cargo can be transported in different ways (road, rail, inland water transport, pipelines), but overall a large capacity with little risk of congestion is interesting from a ports point of view. However, also access to utilities such as energy networks, waste water treatment facilities and sludge deposit areas can be beneficial for a port, for example to meet local environmental regulations. Sufficient infrastructural capacity should be available or easily developed. Pipeline, rail and inland water transport are usually preferred over road transport from an air pollution point of view, which is a key factor in port operations. In fact, more and more ports are prescribing a certain distribution of the cargo throughput over the different transport modalities, with emphasis on the more environmental friendly transport modes.

#### *Waves and (tidal) currents*

Ports have to deal with both short (wind, sea and swell waves, wave periods 4-18 s) and long waves (wave periods >30 s), which can cause vessel motions. Shelter from waves is usually achieved with large breakwater structures. Local tidal flow patterns may include large tidal eddies and strong velocity gradients and internal waves near and in the port entrance that need to be taken into account for vessel manoeuvres. Water level changes due to the vertical tide can cause a port to be (temporarily) inaccessible for deep-drafted vessels. So either the depth needs to be increased or exact tidal time windows need to be forecasted and made available to the ships to enter a port during specific time intervals.

### *Storm prone areas*

Storms impact the accessibility of ports and increase movements of vessels, either via higher waves or direct wind influence on moored ships. In case of storms downtime may increase. As more intense storms may be expected due to climate change, this is an element that needs to be taken into account in the operation and management of the port. However, the spatial scale of selecting another location with a far better (wave) climate is often much larger than the area in which one would locate a port to serve a certain market. Hence, presently in practice storm proneness is usually not a factor that steers the location choice for a new port, but the design and protection levels can be adjusted to the circumstances. Within the framework of this exploratory study, this may be relevant to reconsider.

### **3.3 Influence of morphology on ports and waterways**

For many ports dredging is part of the daily activities and dredging volumes and associated costs remain manageable. However, sedimentation is a big issue for some ports. Berthing and manoeuvring areas and navigation channels need to be maintained by dredging to ensure sufficient depth. Ports function as a sink to silt and sand that originates from the natural system in which the port is located. Maintenance dredging is an issue for many both small and large ports since the costs are high and a critical element in the economic feasibility of a port. For example, Rotterdam needs to dredge about 17 million m<sup>3</sup> per year (Schipper et al., 2010), for maintaining the entrance port and river. This is about 8 times more than in the 1960s, mainly as a consequence of extending the port in a morphologically active area (Rijkswaterstaat, 1987). In many ports the extent of dredging for both construction and maintenance has increased significantly over the past years to facilitate the increasing size of vessels. Dredging is not only a large part of a ports' expenses, often there is also little possibility to increase fees due to strong competition. On the other hand, it can give immediate competitive advantage when neighbouring ports cannot receive large ships. Discussions exist on how dredging costs should be financed, either through general taxes or specific user fees for the use of the harbour, channels and quays and if so, how the fees should be assessed, based on ship size or time in the port? (Talley, 2007). For example in the Netherlands, Rijkswaterstaat is responsible for dredging entrance channels, that is paid by general taxes, whereas the port of Rotterdam is responsible for dredging the port and river itself, that is paid through user fees.

The extent of sedimentation depends on the quantity of sediments carried into the basin or towards the channel and the trapping efficiency of the basin or channel. Different hydrodynamic processes combined lead to exchange of water into a port basin. This can be related to volume exchange due to (vertical) tides, different densities of water and currents (see Figure 3.1). Depending on the flow velocities inside the basin a part of the sediment that is brought in with each water volume (tidal cycle) will settle on the bottom. Maybe stating the obvious, but good to realise: port basins may accumulate sediments, but do not generate sediments. So there is no change in the total sediment in the system simply because the port is there. However, the quantity of sediments is influenced by both 'natural' processes and human land use activities such as deforestation.

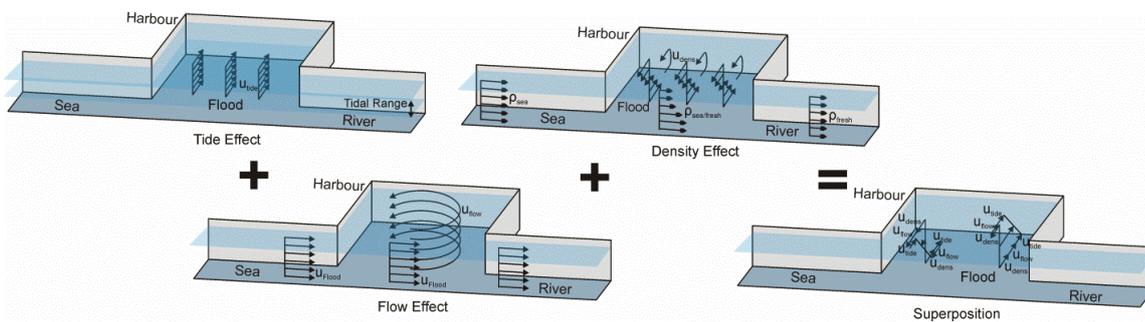


Figure 3.1 Siltation rate depends on tides, density and flows (Source: Deltares).

Besides the solution of dredging to maintain navigation depths, also measures can be taken to reduce the extent of sedimentation. In fact, minimization of sedimentation is usually an important design criterion. This can be done by keeping the sediments out, keep sediment moving or by keeping sediment navigable (i.e. fluid enough, in case of mud). Obviously the location is of importance, but when this is a given, other design parameters related to the port layout could be optimized. Additional mitigation measures that could be taken include mud traps, sand bypassing, extension of port breakwaters, the 'Current Deflecting Wall' (PIANC, 2008a) (Figure 3.2) and 'pile groines' (Figure 3.3) that reduce horizontal eddies in the port entrance and with that the exchange volumes and the sediment supply into the port basin. Dredging schemes could also be optimized. For example, over-dredging reduces the recurrence intervals and via increased efficiency reduction of costs and some environmental impacts can be achieved. However, whether and how overdredging has other adverse effects should be studied further.

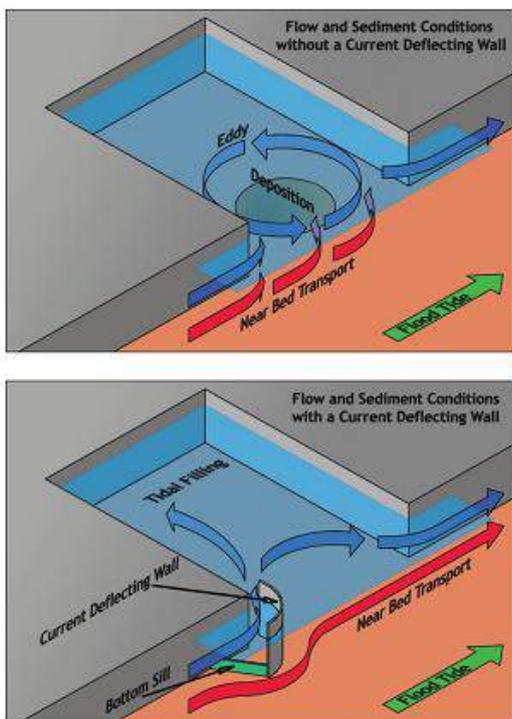


Figure 3.2 Current Deflecting Wall' (PIANC 2008).

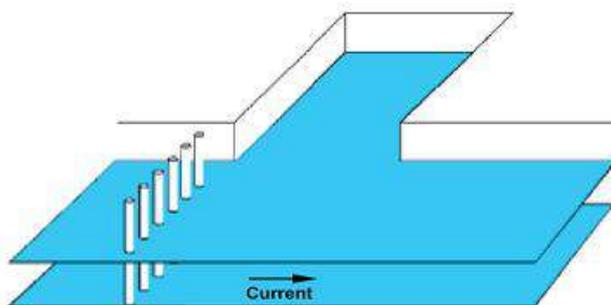


Figure 3.3 Pile Groines (Source: Deltares).

Ports may be planned in a certain area, even when such a region is known for large volumes of silt. The presence of a port may cause the silt to deposit in a different place than it would have in absence of the port. However, when looking at the sedimentation patterns at a geographical scale, a port is an interruption of the process but not necessarily impacts the process as a whole. When the sediments are of such a quality that they can be re-deposited at sea where they would otherwise have been transported to anyway, one could state that the port only temporarily influences the natural process in which a river transports the sediments to the sea. Nevertheless, it may have other impacts, for example on marine fisheries, see also Chapter 2 (Grigalunas et al., 2001).

The impact of a port on sand transports along the coast might be larger as (in case of NW Europe) the north-south stream is interrupted. After some time, via the entrance channel of the port, this sand may enter the port. Locally, large changes in sedimentation and erosion patterns may occur (e.g. erosion of beaches). Depending on where the sand is deposited after dredging, the port has a larger or smaller impact on the morphology.

### 3.4 Impact of changing environmental conditions on port operations in relation to climate change

Impacts of climate change become increasingly visible and are expected to become more pronounced in the coming decades (IPCC, 2014). For ports, direct impacts are related to e.g. sea level rise, the increase of the number and severity of storms and larger variations in river discharges and corresponding water levels. This will be discussed in this section. On the long term, more fundamental socio-economic changes as a response to climate change, such as migration and the type of economies will also impact ports and their operations. However, here we focus on impact of and response to direct physical impacts.

Storms and sea level rise will affect port operations. Sea levels in ports, as well as wind and wave conditions affect the accessibility of the port, motions of ships, the possibilities to moor safely and the usability of quays (downtime). Consequences for ports are that either downtime increases, deep drafted vessels cannot moor due to vertical tides, or that additional measures such as extra mooring lines or other mooring equipment need to be applied. Additionally, quays and dikes may need to be heightened to meet requirements for large vessels. When unable to deliver a certain quality, a port may become less attractive for transport companies and the trade-off is whether this is acceptable for the port or not. With respect to slow rising sea levels, impacts on ports are expected to be low on the short term. Moreover, many ports have been overdesigned in this respect and thus have some margin. On the longer term, port facilities need to be heightened. In practice this can be done when port areas need to be renewed anyway or when new ports will be designed. Rising sea levels can then be taken into account in the design.

For inland navigation the consequences of climate change could be a question of reliability or even of fundamental existence (PIANC, 2008b). Changes in water levels in rivers may affect the number of days per year that the waterways can be used without restriction. When the discharge is low, less depth for navigation is available and so vessels cannot be loaded to their full capacity. When the discharge and water levels are high some bridges cannot be passed anymore. Furthermore, under those conditions navigation might be restricted due to increased flood risk as a consequence of waves caused by ships on dikes. Hence, ports depending on the connection with the hinterland via waterways will be affected. So either their volumes of transshipment decrease or alternatives need to be developed, either by modal shift or by innovating inland navigation. Nevertheless, compared to ports without such a connection to the hinterland, these ports still have a large competitive advantage.

Despite the long-term effects, climate change is not always considered the most urgent issue by many existing ports. Climate change is an incremental process and existing ports can take measures at the moment they consider the impacts will be too high. They may expect that they can 'upgrade' the facilities over time to meet the changing conditions, particularly when they need to be renewed anyway. The reason why climate change is not very high on the agenda may be related to the time horizons ports take into account as commercial organisations. Short term planning typically runs over 1-5 years, whereas the longest outlooks ('master planning') take time horizons of 20-30 years (PIANC, 2014). This is a period in which they expect climate change impacts be managed with existing designs and or adding modifications. The main concerns are storage capacity, water depths and hinterland connections rather than climate change impacts (PIANC, 2014). However, for new ports or port extensions climate change impacts might and possibly should have a role in the design. Port structures (quays, breakwaters) are typically designed to withstand conditions with return periods of up to 50-100 years and so it is logical to take sea level rise, and possibly stronger tides and waves into account. For example, they could increase quay heights and design breakwaters that can survive stronger storms. In Rotterdam many of the port areas even have the same flood defence design level as the dikes protecting the country (i.e. conditions with an average return period of 10.000 years), but that situation will probably be rather exceptional.

The ideal port would be resilient to projected climatic change impacts. Moreover, when reversing the perspective, climate change can also be considered beneficial for the maritime navigation sector. For example, arctic routes that were frozen year-round may become navigable during part of the year.

### **3.5 Conclusions of the influence of morphology on port development**

Port operations, design and location are strongly interlinked. In this chapter we looked into several location-specific factors that affect the operation and management of ports. When deciding for a port location several criteria are of importance, including maritime conditions such as water depth and waves, morphological conditions such as sand availability and the influence of estuary, climatic and geographic risks, inland transport access, distance from sea route and environmental impacts (Port Consultants Rotterdam, 2014). Table 3.1 gives a summary of location-specific factors that may affect a ports design and operation and thus should be considered when deciding for a port's location.

Table 3.1 Influences of the physical environment on a port's design and operation and therefore play a role in achieving a no-impact port.

Location element	Impacts on design and operations
Sandy or Rocky coast	<ul style="list-style-type: none"> <li>• A sandy coast is less costly to dredge and new land may be reclaimed. However, dredging remains required</li> <li>• In case of sufficient natural depth no need for dredging to create and maintain depth as long as one does not interrupt wave and flow patterns</li> <li>• Most coasts consist of a mix of sand and rock</li> </ul>
Estuary or closed coastline	<ul style="list-style-type: none"> <li>• Access or to inland waterway and productive hinterland</li> <li>• Influence on water and soil quality of port and sedimentation (river may transport pollutants and contaminated soil)</li> </ul>
Presence of infrastructure	<ul style="list-style-type: none"> <li>• Sufficient capacity needs to be ensured</li> <li>• Use and develop (if absent) different transport modalities (pipeline, waterways, road, rail)</li> </ul>
Exposure to waves and tidal currents	<ul style="list-style-type: none"> <li>• Vessel motions at berths may affect offloading efficiency</li> <li>• Complex currents (strong gradients, eddies) will influence vessel manoeuvres</li> </ul>
Exposure to storms	<ul style="list-style-type: none"> <li>• Increase movements of vessels due to waves and wind</li> <li>• Increase of downtime</li> </ul>
Morphological situation	<ul style="list-style-type: none"> <li>• Coastal structures may locally disrupt natural morphological patterns: beaches may erode and the port functions as a sink of sediments from the natural system</li> <li>• Sedimentation reduces depths of entrance channels and berthing areas</li> <li>• Sediments can be removed (dredging) or extent of sedimentation reduced (mitigation) – e.g. mud traps, CDW, extension of breakwaters</li> </ul>
Sea level rise	<ul style="list-style-type: none"> <li>• Vertical tides can make a port temporarily inaccessible for deep-drafted vessels</li> </ul>
Variation in river discharges	<ul style="list-style-type: none"> <li>• Reliability of inland transport may be reduced due to climate change, even up to its fundamental existence</li> <li>• High water levels: bridges cannot be passed or vessel traffic is seized for flooding safety</li> <li>• Low water levels: vessels cannot be loaded fully</li> </ul>

All of the location-specific factors described in Table 3.1 impact the design and operation of ports and therefore play a role in achieving a no-impact port. In practice, dominant decision criteria for the location for developing port capacity (so either through new ports or port expansion) are often a mix of socio-economic, governance and physical criteria, such as connection to hinterland (where it is located, how it can be accessed), existence of infrastructure and attitude and influence of authorities. After deciding for a location, other location specific characteristics are taken into account in the design and operational plans, or altered if possible and desirable. For example, sedimentation is an important factor in port design and operation. Sometimes, the sand can be used to develop the port, but ports also function as a sink for sediments. To maintain enough depth, mitigation measures can be taken, but dredging often remains necessary in many ports. The extent of sedimentation depends on the quantity of sediments carried into the basin or towards the entrance channel and their trapping efficiencies. Next to an economic argument, also for environmental reasons

reducing the need for dredging is of interest. To reduce impact of storms and waves protective structures can be constructed or innovative mooring techniques can be applied that ensure small vessel motions also under more severe environmental conditions (Bakermans et al., 2015; De Jong et al., 2014). These issues are usually not directly determining the location of a port.

From sustainability and a no-impact viewpoint, it would be desirable if the location choice would be part of the design process and sustainability variables since the two are closely connected and they have implications for the operational management. For example, depending on the location, depth needs to be constructed or a certain level of natural depth can be used, sedimentation strategies need to be developed, and the downtime can be influenced by the occurrence of storms. However, as noted before, limitations are put on the search for a location by the scale and the purpose of the port. A port must be able to serve its intended hinterland. Hence, usually the upper limit of the search scale is in the order of 100kms. After knowing the search area, one can search for favourable local conditions such as the presence of natural depth, infrastructure and hydrodynamic conditions. However, due to a difference in scales at which physical processes occur relative to spatial scales of practical aspects, elements like storms or sea level rise do not change within the area considered for selecting a port location and thus from that point of view it does not really make a difference to locate a port elsewhere within practical boundaries (targeted hinterland). Which criteria should be leading from a sustainability point of view, and where economy and ecology are in balance, should be further studied. However, that is beyond the scope of the present exploratory study.

## 4 Port management models and governance

### 4.1 Introduction

No-impact ports have the same functional requirements and operate in the same governmental systems as traditional ports do. In chapter 4, we therefore define the function of a port and how it operates in the market and we elaborate on the management models of ports. This will give insight into possible incentives for developing a no-impact port from a market and management point of view.

The location and design of a port are strongly related to the activities it needs to facilitate. Activities can be limited to one type of cargo or a combination of many different cargo streams and to primarily export or import/ transshipment. Typically, a mining company that has its own port for exporting the raw materials to ports elsewhere wants the harbour close to the mine and suitable for the ships that can carry the materials. A port like Rotterdam, that is mainly a transshipment port for all types of goods and in which multiple industrial activities take place, should be able to host different types of vessels and in particular should have good access to its hinterland. In general, for ports dedicated to a single type of cargo, and particularly when it concerns tanker cargo, more options are possible in terms of design than for container terminals. Container terminals are more stringent on wave and current conditions (PIANC, 2012).

The motivation of an authority for port development is usually the economic development of their region. The choice for a location for a public port is typically constricted by the borders of the administrative region by which the port is sponsored. The question is who has the authority to decide. Of course the combination of being good neighbours and historical development can contribute to further developing ports in another country if this is cheaper or faster. For example, for the German Ruhr area it is interesting to encourage or even invest in the port of Rotterdam and its infrastructure. For private ports administrative boundaries are less of a determining factor, but they have to find an area where they could construct and get the permits. Additionally, the extent to which authorities are cooperative or even willing to invest in for example connecting infrastructures (e.g. inland waterways, roads) and have more or less stringent (environmental) legislation are important factors. The more stringent the legislation is, the more actions need to be taken by the port authority.

In the past, port locations were decided upon based on the presence of economic activities and natural shelter, such as in a bay or estuary. Notteboom and Rodrigue (2005) have developed a port development model, based on the initial model of Bird (1980) that describes the process of setting-expansion-regionalization-specialization. They adjust the model to more contemporary port development that includes the emergence of hub terminals off shore or island locations without significant hinterland, and they include inland distribution systems as a driving factor for port development. Ports are specialising in one function due to geographical considerations such as proximity and intermediacy to production and consumption. Hence, the phases port development in their model are 1) scattered ports, 2) penetration and hinterland capture, 3) interconnection and concentration, 4) centralisation, 5) decentralisation and insertion of offshore hubs and 6) regionalisation.

*Markets in which ports operate*

A port supplies a service on a market where there is demand for this specific type of the “moving goods”. In geographic terms the market which a port is serving is its hinterland. The hinterland spans the range of origins and destinations which demand transport services from the particular port. A distinction can be made between captive and contestable hinterlands. De Langen (2007) clearly describes this distinction: “*All regions where one port has a substantial competitive advantage because of lower generalized transport costs to these regions belong to the captive hinterland of this port. Consequently, this port handles the vast majority of all cargoes to/from these regions. Contestable hinterlands, on the other hand, consist of all those regions where there is no single port with a clear cost advantage over competing ports.*” As a consequence, ports compete over market share in the contestable hinterland.

In contestable hinterlands, shippers base their choice of transport route (and therefore port) on the generalized logistic cost of the full transport chain from origin to destination. As ports seek to increase volume, an objective of ports is to bring down generalized costs. Due to competition this incentive is most powerful in ports serving contestable hinterlands. In captive markets volume growth cannot be achieved by lowering costs and therefore costs are of less importance. When considering the financial viability of ports it is important to be aware of the type of market a port operates. Especially when the port is operating in a contestable market where competition over price is fierce investment costs matter.

#### 4.2 Port management models

When considering financial viability of basic infrastructure in a port, it is essential to distinguish the several stakeholders within a port and their objectives. Port management (World Bank, 2013) is structured around the ownership, the administrative management models and the regulatory frameworks of ports. Generally four major types of port management exist in which those stakeholders can operate.

- The public service port model
- The tool port model
- The landlord port model
- The private sector port model (also referred to as the private sector service model)

##### The public service port model and the tool port model

In these models, the Port Authority owns the land, the fixed and mobile assets, and performs regulatory and port functions. The port is controlled by a governmental body.

In the public service port model, the same organization has the responsibility for developing the basic infrastructure, superstructure (such as terminal buildings) and equipment, as well as executing the operational activities. There is a heavy dependence on government funding. If there is not sufficient funding or the limited funding is not well spend it leads to underinvestment which has a negative effect on port performance. On the other hand, government funding allows for the inclusion of negative external effects in the business case.

The tool port model is similar to the public service port model. The only difference is to be found on the operational side, where private companies are allowed to offer loading and unloading-services to visiting ships.

For the purpose of this study no further differentiation between the public service port and the tool port is made.

The main stakeholders in these models are the port authority which is directly controlled by the government (often the Ministry of Transport or its equivalent). The port authority receives a budget from the government to fund construction and expansions. Because benefits are often allocated to the economy as a whole, funding in these cases is supplied in the form of subsidies and do not always need to be repaid. This port management model can be found in Sri Lanka, India and Tanzania (service ports) and Bangladesh (tool port). The number of service and tool ports however is declining as noticed by the trust fund Public-Private Infrastructure Advisory Facility (PPIAF, 2015) that provides technical assistance to governments in developing countries.

#### The landlord port model

In the landlord port model, the public Port Authority retains the ownership of the port's basic infrastructure (such as breakwaters, quays, basins and connecting infrastructure). Quays are leased out to private operating companies. The Port Authority is still responsible for the economic management of the port and the maintenance of basic port infrastructure, including wharves, berths and access roads.

The private operating companies provide and maintain their own superstructures, their equipment and their information systems.

The main stakeholders to be dealt with are the public port authority and private terminal operators. Also in this model funds for investments in basic infrastructure can be supplied by the government in the form of subsidies. Investments in terminals are made by terminal operators and rely on a viable business case. An important advantage is that the contractual relation between the port authority and the terminal operator allows for clauses on how the terminal should be used, for example to limit CO2 emissions.

#### Private sector port model (private sector service model)

In this model, the public sector has no longer an interest in port activities or leaves port management and operations entirely to the private sector. Port land is owned or bought by the private sector and all operational activities are performed by the private sector.

Two types of private ports exist: those which are built to support the core-activities of a private company (for example a port next to a mining site) and which are often regarded as a cost-centre (e.g. the port itself does not need to be profitable) and ports which themselves are meant to make a profit.

The main economic advantage of the private model is that port development tends to be market oriented. The main disadvantage of the private sector model is the risk of creating an abusive monopolistic system and the suppression of public involvement in the development of ports within a longer term economic policy. It also makes it more difficult to impose policies of green development as long as these policies are not made into law and regulations.

The main stakeholder in this model is the (private) port authority. In permit-issuing there is a role for the government. Investments are assessed thoroughly. This allows for an assessment of risks, both in the long as in the short term and opens up the opportunity to consider risks as result from climate change.

The private sector port model is often found in remote, specialized ports (for example in Australia) and privatized ports in for example the UK, the Indian province of Gujarat and Africa.

#### 4.3 Summary role of governance in port development

This chapter elaborates on markets and port management models and investigates to what extent this influences the viability of a no-impact port.

The location of a port is not only bounded by physical constraints that are outlined in chapter 3, but also majorly influenced by socio-economic and political criteria. Determining factors are the location and accessibility of the market and the availability of territory (Notteboom et al., 2009). Moreover, port developments often continue historical developments (which type of economy, which location) and there will be a certain level of path dependency. Most existing ports will focus on increasing capacity within or near the existing port area. Location can be decisive in whether or not a port is a no-impact port, but currently not a choice factor. Requirements concerning the location may be a barrier to no-impact developments.

The market in which a port operates by itself should not limit the opportunity for no-impact port development. If the costs of port development increase due to environmental standards, in a captive market it would be easier to pass on any additional costs to shippers. For ports in contestable markets this is more difficult and costs will likely be passed on to the government.

It should also be noted that the design process and the location choice are often disconnected. The port authority often decides for a location and then asks an engineering company to design a port on that specific location.

All of the port models considered, allow for the development of green port models and therefore potentially no-impact ports. The 'governance' as such, does not prevent green ports to be developed. However, we need to consider that 'no-impact ports' generate 'green benefits', which largely do not go to the port itself but to the society as a whole. The port benefits from this as well, profiting of increased public acceptance. In the 'public service port/tool port' and the 'landlord port', public sector involvement allows for relatively easy implementation of 'green standards' as long as required funds (subsidies) are made available. Also publicly-run ports can decide to incorporate the negative externalities in the business case, effectively internalizing them. This makes the negative effect visible and therefore acts as an incentive to find alternative 'green' designs. Privately funded ports offer opportunities to develop alternative ports without additional government spending. A strong regulator (e.g. a strong government) is of importance though to set the boundaries within which developments can take place. Otherwise, and under the assumption that no-impact ports require considerable higher funding, there is no convincing incentive for the private operator to develop a 'no impact port'.

## 5 Socio-economic rationale of port development

### 5.1 Introduction

In recent years, there has been a growing awareness of the impacts of investments on the ecosystem, resulting in a greater understanding of the relation between impacts on the ecosystem and the effect on human welfare. Since governments tend to make investments that will improve the country's social welfare, governments are interested in this type of information. However, an investment can be a good idea from a social welfare point of view, but not from a financial point of view. This chapter presents an introduction to the concept of a no-impact port from a socio welfare and financial perspective. A large part of new port developments will take place in emerging economies and developing countries. These countries are expected to build an important part of their infrastructure in the coming two decades. The choices that they will make will determine future options and vulnerabilities of this infrastructure, for example the ability to adapt infrastructure to future climate change or socio-economic and demographic developments. One of the challenges will be to develop port infrastructure with minimal negative external consequences. Insight in the impact of a port on the social welfare of a country can be used to determine which impacts need to be minimized. On the other hand, it may give the rationale for governments to invest in another type of port. Additionally, the general finance mechanisms and risks from the perspective of an investor need to be determined in order to get an idea of the implementation possibilities. These points are reflected in the next chapter. This chapter starts with a consideration of the Social Cost Benefit Analysis (SCBA) to capture the economic costs and benefits of a port to society as a whole. The second part elaborates on a much narrower perspective, considering the financial costs and benefits to an investor. The chapter is divided in the following sub-chapters follows:

- 5.2 gives the set up of the Social Cost Benefit Analysis and the financial analysis of port development.
- 5.3 gives an indication of both the physical effects (e.g. a reduction in water quality) and the welfare effects (e.g. impact on ) of port development by using the ecosystem service concept.
- 5.4 gives an indication of the construction costs, maintenance and operation costs of ports to give an idea about the amount of money involved in this sector.
- 5.5 shows a summary of the results of the SCBA
- 5.6 elaborates on the potential consequences to the business case of a no-impact port. This business case is considered from the perspective of the investor.

### 5.2 Social Cost Benefit Analysis and financial analysis of port development

In general, profit maximization is generally understood to be the objective of investments in the private sector, whereas maximization of net social benefit is the overall objective in the public sector. In view of this last objective, a SCBA is frequently used to support decision making in many types of public (investment) projects. The SCBA helps to predict whether the societal benefits of a policy or investment outweigh the costs (under a certain pre-determined discount rate), and compares the costs and benefits between alternatives. A SCBA includes the effects on the ecosystem by estimating the change in social welfare due to ecosystem changes. Typically, the best outcome is the alternative that increases (public) welfare the most (Romijn and Renes, 2013).

While the SCBA will give insight in the benefits for society in general of developing a no-impact port, a financial analysis will focus on value of elements of ports and port operations

from a business perspective for each stakeholder participating in the investment. Businesses will be focusing on the business case considering the risks of an investment and valuation of future cash flows. Insight in the rationale of companies and public financiers will be very important for the possibility of implementing a no-impact port.

In summary, a positive business case not necessarily means a positive societal cost benefit analysis, and vice versa. An investment can be beneficial for the investors, but displacement of negative effects on the ecosystem can result in a negative social and cultural welfare effect. It also works the other way around, even though a project has a positive societal cost benefit analysis, it does not have to be a good investment for the stakeholders participating in the investment.

This study aims at providing an insight into the possibilities to receive the most social welfare from the development of a port, without negative effects on the ecosystem and at the same time realising a positive business case. An understanding of the social costs and benefits of a traditional port will give an indication of the design adjustments that can add the most social welfare and least ecological impact? The financing hurdles and opportunities will give insight in the main factors determining a positive business case for port developments, both from the perspective of a public as from a private investor.

#### *Set-up Social cost benefit analysis*

Therefore, the first part of the study provides an indication of the costs and benefits of a (traditional) port from a public welfare perspective. We will do this by first describing both the costs and potential effects of port development on a natural coastal ecosystem, after which we will give an indication of the welfare effects.

Since this study has an explorative character, we express the costs and benefits in qualitative terms. Therefore, we will not be able to estimate a cost-benefit ratio. In order to be able to determine the (welfare) effects of the development of a port, we need to describe the reference situation. In general this is the situation without a project, which is in this case the situation without port development. In the reference situation we assume that worldwide trade will slowly increase (International chamber of shipping, 2013), while other factors keep constant. This reference situation will be compared with the development of a traditional port. The characteristics of a traditional port are described in chapter 1.4. Finally, the reference situation will be compared with a situation with port development, which will give an indication of the factors that add most to social welfare. The study will consider the impact of a port on the social welfare of a country and on general social welfare.

#### *Set-up financial analysis*

The second part of the study comprises a description of the general hurdles in the financing and opportunities for a no-impact port.

We describe how the difference in timing for having to pay the costs for basic infrastructure in ports and receiving the revenues, results in a need for financing. Projects always need to be viable. A project is economically viable when the SCBA yields a positive result. A project may be economically viable but not financially viable. In this case a *viability gap* exists. In ports in Western Europe where competition between ports is fierce, subsidies are always needed to bridge this gap. In other (mainly underdeveloped) markets the project can be both financially viable as economically viable.

By supplying basic infrastructure to ships and charging port users for this, infrastructure creates revenues. Revenues will only be created when the port is in use. Before this the port

needs to be constructed, which requires funds. The timing difference between the moment funds are *spent* on construction and the moment *revenues come in* creates a shortage of cash. In the figure below, on the left, the timing difference between expenditures and spending which creates the shortage is shown. The negative cash flows during the operations phase represent maintenance costs (Fig 5.1). Because of the time value of money an euro/dollar earned in the future won't be worth as much as one earned today. This is captured by applying a discount factor to future cash flows which comprises assumed risk, opportunity costs and inflation.

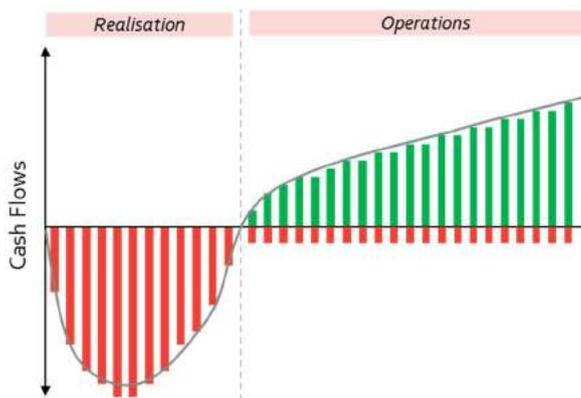


Figure 5.1 (nominal) cash flow during the lifetime of a project. Source: Rebel.

Financing needs to be found to bridge the timing difference between expenditure and income. Otherwise the project will not be realized. Two types of financing are described in 5.5.4 and 5.5.6 respectively: public financing and private financing.

### 5.3 Determining social benefits by evaluating ecosystem services related to port development

This chapter aims to give an indication of both the physical effects and welfare effects of port development. We will first indicate the ecosystem services present in a natural coastal ecosystem. The selected ecosystem services can be seen as the reference situation. Afterwards, we identify the effect of a port on ecosystem services to finally describe the effect on welfare. This can be seen as a first step in the valuation of the effects of a port on coastal and marine ecosystems.

#### 5.3.1 Ecosystem services approach

To assess the welfare aspects of an existing coastal ecosystem, we make use of the ecosystem services approach, in which functions of an ecosystem are translated into the benefits for humans. Figure 5.2 adds important ecosystem services to figure 2.1 in chapter 2. The figure demonstrates that the characteristics and functions of the ecosystem have to be determined first, before being able to give an indication of potential change in the ecosystem services

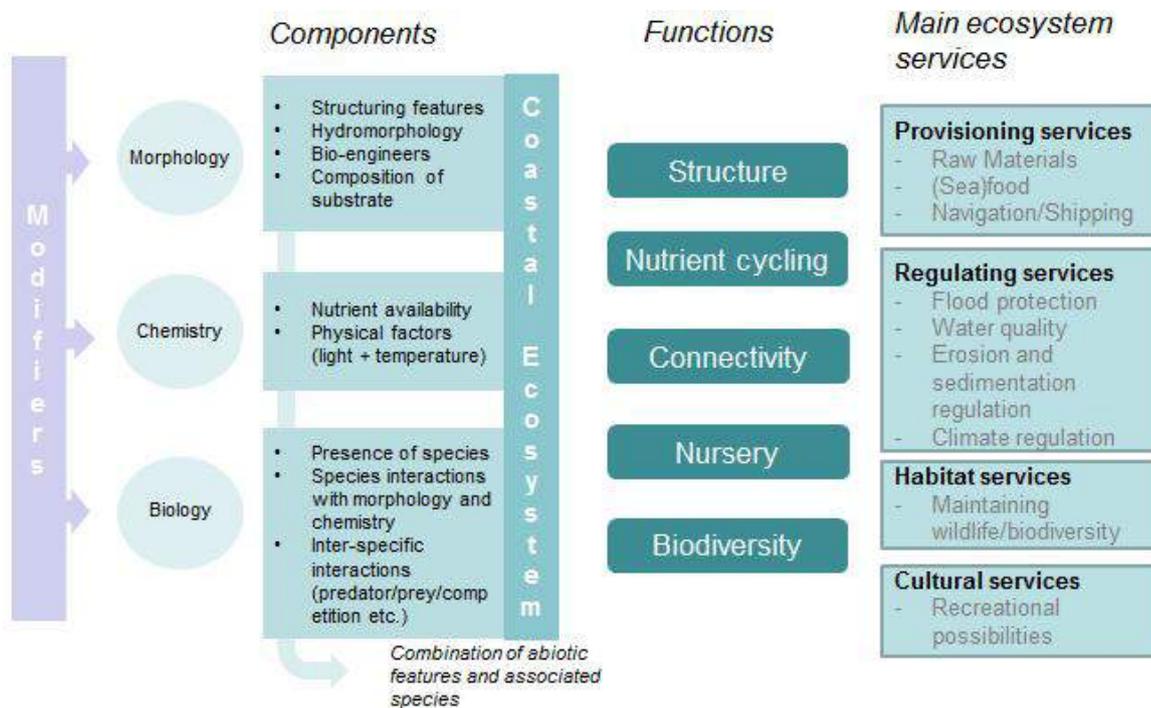


Figure 5.2 Characteristics and functions of the ecosystem in ports with the indication of available ecosystem services (Deltares, 2015).

The most important ecosystem services present in a natural coastal ecosystem are collected from both literature and chapter 2 (Barbier et al., 2011; Luisetti et al., 2009; Jacobs et al., 2014). The selected ecosystem services are seen as frequently occurring services in a natural coastal ecosystem. These ecosystem services may be affected by the development of a port. The extent to which these services are affected depend on the port development and the abundance and quality of the services at this location. Since we will not develop a case study and thus cannot describe a specific starting situation; we will not be able to give a quantitative indication of changes. Therefore, we cannot value these changes. However, we will make some wide-ranging statements about the effect of a port on the ecosystem services present in a natural coastal ecosystem, based on the information presented in chapter 2, expert knowledge and additional literature. After identifying the effect of a port on ecosystem services, we will be able to describe the effect on welfare.

### 5.3.2 Effects of a port on ecosystem services

The next section shows the frequently occurring ecosystem services in a natural coastal ecosystem. A small description of the ecosystem service appears in *italics*. After which we give an indication of the effect of a port on the specific ecosystem service and the accompanying effect on social welfare. The value of the different ecosystem services is part of the effect on social welfare. However, as previously stated a quantitative valuation of the changes is not possible at this stage, due to the lack of information referring to the reference situation and changing conditions at a specific location.

#### Provisioning services

1. Raw materials

*Provides sand/gravel.*

Effect on ecosystem services

The construction of a port basin and breakwaters reduces currents, which enhances sedimentation of mainly sand and sludge. Sand may be used for housing, public works, sand nourishment and road construction (Maes and Schrijvers, 2005). Sedimentation of sand nearby a port offers better possibilities for extraction. However, the material has to fulfil certain quality conditions that have to be met before the material can be extracted for certain use. A port can negatively influence the quality of sand. Altogether a port will probably not have a significant effect on this ecosystem service.

#### Impact on social welfare

Humans are able to extract the same amount of sand with or without a port. However, a port allows more sedimentation at a location easier to reach, which will reduce the costs of extracting sand. Since the costs of sand comprise mainly the costs of transportation (Briene et al., 2012) the reduction in costs can be substantial. However, harbour sediments are often contaminated with POPs, PCBs, PAHs, TBT, mineral oil and metals (Stronkhorst and Van Hattum, 2003; Alvarez-Guerra et al., 2007, Schipper et al., 2010), which will limit commercial use. Therefore, the value of the benefits of this additional sedimentation is probably small. The main reasons are the relatively low amount of additional sedimentation due to the port as well as the limited possibilities for commercial use. In case dredged sand is sold, the potential value can be found by estimating the reduction of the costs of dredging.

### 2. (Sea)Food

*Provides suitable reproductive habitat and nursery grounds for fish, shell fish etc, which humans can catch and eat.*

#### Effect on ecosystem service

As mentioned in chapter 2, in a natural coastal ecosystem fish and shellfish can be abundant in high numbers due to the high productivity of the coastal ecosystem. Especially, a number of habitats such as mangroves, corals and sea grass are known to have important nursery grounds functions for fishes (Nagelkerken et al., 2000; Lee et al., 2014). Development of a port has the potential to remove or disturb current habitats, decrease connectivity and potentially reduce water and sediment quality, depending on location and mitigating measures. As a result, in locations that contain habitats with nursery functions and contributed to recruitment of fish, impacts of port development could potentially negatively affect fish stocks. Additionally introduction of invasive species in ballast water<sup>1</sup>, such as jellyfish species may compete with fish for food and other resources, which may negatively impact the fish stock (Walsh, 2015). In general, we expect that a port will decrease this ecosystem service.

#### Impact on social welfare

A port is expected to decrease the ecosystem service (sea) food. However, the degree of the reduction of seafood affects largely the reduction in value. A small decrease will probably just locally affect fisheries, which will just reduce the turnover of fishers. However, when a port is built at a very important nursery ground or migratory route, connectivity and functions could be lost which could potentially affect fisheries on a larger scale. Possibly this influences the market price of fish, which may result in higher turnover for fishers and higher prices for consumers. Overall the negative benefit will be probably small. However, if a port would result in an increase in fishing pressure due to the ability to sustain a larger fishing fleet, effects on fish stocks could potentially be significant.

### 3. Navigation/shipping

*Provides water and depth for navigation*

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<sup>1</sup> In some countries this is regulated. However, not in all countries this regulation is implemented.

## Effect on ecosystem service

A port may slightly decrease the possibilities of navigation due to sedimentation that reduces water depth [Deltares, 2010b]. Therefore, a port may slightly decrease this ecosystem service.

## Impact on social welfare

A port may slightly decrease the possibilities of navigation due to sedimentation that reduces water depth. Since a port has direct interest in keeping this ecosystem service in a good condition, a port authority will take measures to keep the necessary water depth. The costs of this dredging activity can be seen as the negative benefits of the effects of a port on this ecosystem service. Since these costs will be part of the maintenance costs of a port, the welfare effect will be neutral.

## Regulating services

### 4. Flood protection

*Attenuates and dissipates waves, reduces sea spray and drains river water.*

## Effect on ecosystem service

A coastal ecosystem can provide natural flood protection. Structures such as gravel bars and sand dunes and ecosystems such as salt marshes, mangroves and vegetated fore shores may attenuate waves, and as a result contribute to flood protection (Mueller et al., 2014; Groot et al., 2014). If such a structure or ecosystem is removed to develop a port, natural flood protection will be locally reduced. However, without a natural flood buffering structure or ecosystem, the development of a port may improve flood protection due to the construction of quays. Although the impact depends on the presence of flood protecting structures, in general we assume that this ecosystem service will slightly decrease due to the construction or expansion of a port.

## Impact on social welfare

The impact of decreasing flood protection depends on the consequence of a flood. For example, if many people live in an area that will have a greater chance to be flooded due to the construction of the port, the potential damage will be higher. This higher potential damage can be seen as the negative benefits of a decrease in flood protection. However, to obtain a negative benefit the chance to be flooded has to (significantly) increase. Additionally, the extent of the (negative) benefit depends on the reference situation. For example, the value of mangroves as coastal protection may be as much as 300.000 US dollar per kilometer of coastline (Barbier, 2011). On a small negative benefit due to a slightly higher local chance of flooding is likely. However, the negative benefit will be higher in highly populated areas, which are frequently the areas of port development. In case of a natural coastal system that hardly support flood protection, development of a port can even positively affect flood protection.

### 5. Water quality and/or purification

*Provides water filtering, water purification*

## Effect on ecosystem service

Organisms of the coastal ecosystem have the potential to positively affect water quality due to their ability to cycle (and store) nutrients. As mentioned in chapter 2, ports may have a negative effect on water quality due to pollution incidents, anti-fouling, ballast water treatments, organic discharge, loss of habitat for benthic communities and sediment re-suspension. Therefore, we assume a decrease in water quality due to the development of a port.

#### Impact on social welfare

A new port location will be a new source of pollution and eutrophication. Additionally, it will reduce the ability of the system to cycle nutrients. This all will reduce the water quality, which will impact fisheries, tourism and human health. In case water quality will influence fish stocks, fisheries will be affected (see for impacts on welfare the ecosystem service (sea)food). There can only be a health impact if humans are exposed to reduced water quality. Therefore, the use of the coastal ecosystem by especially fisheries, recreationists and tourists will determine the impact. If humans are exposed to endemic diseases and high concentrations of nutrients, this can pose serious health risks. Economic (negative) benefits of health can be measured by take into account parameters including productivity loss, treatment costs and the value of deaths. Additionally, water pollution can result in large losses in tourism revenue. For example the World Bank (2003) estimated that the total loss from water pollution in the Philippines is annually 940 million euro. In case a port is developed in a freshwater system it may also impact the quality of drinking water and may impact the productivity of the agricultural sector (UNEP, 2010).

#### 6. Erosion and sedimentation

*Provides sediment stabilization, soil retention*

##### Effect on ecosystem service

Typically, the morphology of a natural coastal ecosystem is in balance. Port development may interrupt this balance (Deltares, 2010). For example, sedimentation in the port may occur due to bypassing sand from the breaker zone, which may increase local erosion. The extent of disruption of the sand balance depends on the design characteristics of the port. Disruption of the sand balance will be particularly present at sandy shorelines (see chapter 3.3). Additionally, some organisms are capable to create structures that stabilize soft sediment; disturbance of their habitat may reduce erosion and sedimentation regulation. In general we expect a disturbance of the natural erosion and sedimentation processes of the ecosystem.

#### Impact on social welfare

A port may disturb erosion and sedimentation regulation. In case of disruption of the sand balance, some locations will face more sedimentation, while other locations will face more erosion. The impact depends on the locations encountering sedimentation or erosion. For example, if a disruption in the sand balance implies erosion of a touristic beach, the welfare effect will be much larger than if it will imply erosion of deserted land. Therefore, we cannot say anything about the economic impact yet.

When sedimentation reduces the water depth within a port, the port authority will perform dredging. Although, at first glance the cost of dredging is seen as a negative benefit, these costs will be part of the maintenance costs of the port. Therefore it will not have a negative effect on social welfare. Note that this ecosystem service is almost not affected on rocky shorelines.

#### 7. Climate regulation

*Carbon sequestration and burial*

##### Effect on ecosystem service

Mangrove forests, sea grass systems and algae can sequester carbon in coastal ecosystems. Disturbance of these ecosystems may reduce sequestration and therefore burial. Although eutrophication in ports may temporarily result in an increase of carbon sequestration, on the long term ecosystem stability will reduce, which possibly result in a reduction of carbon sequestration and burial.

### Impact on social welfare

A port will have a slightly negative impact on climate regulation due to disturbance of the carbon sequestering function. Since this impact is mainly present at the location of the port, the overall impact will be small. However, the impact of a port depends on the presence of ecosystems with a high carbon sequestration potential, such as sea grasses and mangroves. In case this ecosystem services are replaced, the negative benefits may be significant. The welfare effect of a reduction in carbon sequestration can be expressed in the market price of carbon, which differs between 1 and 168 tCO<sub>2</sub> depending on the country (Worldbank Group, 2014).

### Habitat services

#### 8. Maintaining wild life/biodiversity

*Provides a habitat for (migratory) species, biological productivity, diversity; habitat for both wild and cultivated animals and plant species.*

### Effect on ecosystem service

As mentioned in chapter 2, coastal ecosystems are high in biodiversity. Habitat loss and changing environmental conditions (e.g. reduced water quality) due to port developments may reduce biodiversity. However, this depends on the reference situation. Besides the negative effects on biodiversity, a port may provide new habitats which may increase biodiversity. This also applies for invasive species. A port can function as a stepping stone for unwanted or plague species to invade nearby zones.

### Impact on social welfare

Port development may reduce biodiversity due to changing environmental conditions (e.g. reduced water quality) and habitat loss. The impact on social welfare depends on the effect of changes in environmental conditions on wild life and biodiversity. For example, if reduced water quality affects nursery grounds for fish, species dependent on this fish will be affected, such as seals and birds. Since people value the presence of these species, the impact on nursery grounds may have a much larger impact on humans than just the single impact of a reduction of nursery grounds. Loss of habitat may also affect biodiversity. The impact depends on the type of habitat. For example mangroves, coral reefs, seagrasses and oyster reefs will support more biodiversity than pelagic marine systems. Additionally, the welfare effect of a loss of this type of ecosystems will be higher. However, humans value different species different. For example, charismatic species, such as seals, whales and birds are valued higher than most benthic organisms (Ressurreiaco et al., 2012). A reduction of charismatic species implies higher negative benefits than the reduction of other species (Barbier, 2011). Overall, the value people attribute to species, together with the value of food provisioning services determines the impact on social welfare.

### Cultural services

#### 9. Recreational possibilities

*Provides unique and aesthetic landscapes to recreate*

### Effect on ecosystem service

Coastal ecosystems are popular places to recreate. Reduction of biodiversity (mainly charismatic species), water quality and area to recreate due to the development of a port will impact the possibilities to recreate. Additionally, a port may affect the amenity value of the landscape. However, improved accessibility may attract recreationists to the area around the port.

Overall, the challenge is how to develop an ecosystem-based management plan in the port for recreational possibilities with integrated options as recreational fishing, tidal park or port tourism.

#### Impact on social welfare

A port may reduce water quality, occupy marine space, reduce biodiversity and displace wild life, which may impact recreation possibilities. However, the accessibility of recreation spots around the port will probably increase, which may increase the number of recreationists.

The port will occupy a part of the land that could be used as recreation space. If this was already a recreation area, the port will negatively impact tourism. In addition, the quality of the ecosystem around the port will be probably reduced, which will reduce the value of tourists for this destination. The welfare effect depends on the presence of alternative locations for tourists within the country. If there are multiple alternative locations, the effect of a reduction of recreational possibilities will be limited. However, when there are no or few alternative locations the welfare effect can be large. In addition, if either the number of charismatic species is reduced or this species are displaced, the general value will be reduced (see maintaining wild life/biodiversity).

Based on the described ecosystem services we are able to present the effects of port development<sup>2</sup> on the ecosystem services. Although the condition of this natural coastal ecosystem (reference) before the construction of the port will determine whether ecosystem services increase or decrease, we give an indication of the possible impact of port development. In addition, we give an indication of the potential effects of the changes of the different ecosystem services on social welfare. Table 5.1 gives an overview of both the potential physical effects and welfare effects of the construction or expansion of a port on financial benefits and ecosystem services.

### 5.3.3 Other effects of a port on the environment

The following effects are disturbances due to port development. Since these effects are not directly related to a service the ecosystem delivers, we treat them separately.

#### Air pollution

##### *Effect on environment*

The infrastructure associated with marine ports is a source of air pollution<sup>3</sup> (see chapter 2). Since construction or expansion of a port will increase associated infrastructure, air pollution will increase. On the other hand the construction of a port will probably reduce inland transport, which reduces air pollution. In case of expansion of a port this effect will be present to a lesser extent. Not developing a port will probably result in an increase of inland transport, which in general will result in more air pollution (Transport Research Knowledge Centre, 2009). Whether the effect of a port on air pollution is either positive or negative depends on both factors.

However, much progress has been made to improve air quality in port areas by reducing emissions. For example, the port of Rotterdam has implemented a number of rules and measures to improve air quality. Dynamic traffic management to reduce traffic jams has been incorporated in the design of the Rotterdam port area. Furthermore, cleaner ships are

<sup>2</sup> A description of a traditional port development can be found in chapter 2.

<sup>3</sup> We consider PM10, SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub>

charged 10% less when they meet certain ISO-standards. (Rotterdam Office for Sustainability and Climate Change, 2011).

#### *Impact on social welfare*

Negative effects arising from reduced air quality at port areas could have both chronic and acute effects on human health. Air pollution has been associated with lung cancer, heart disease, respiratory disease, asthmatic attacks and reduced life expectancy (Kampa & Castanas, 2008).

The impact of air pollution on welfare depends for a large part on the type of air pollution and the exposure to humans. For example, the health effect of particulate matter is different than the health effect of NO<sub>x</sub>. In addition, if humans are not exposed to a certain concentration of these pollutants, there will be no health effect. The exception is CO<sub>2</sub> emissions that affect in a more or lesser extent all humans by the effects of climate change. Economic costs of health can be measured by take into account parameters including productivity loss, value of reduced quality of life and the value of loss of life years. The costs of CO<sub>2</sub> emission can for example be estimated by using the market price of CO<sub>2</sub> (see ecosystem service climate regulation).

#### Noise pollution

##### *Effect on environment*

Construction or expansion of a port will negatively affect noise pollution (see chapter 2). To this respect, much progress has been made to reduce noise pollution from port development. For example, in the port of Rotterdam, low-noise surfaces have been used for roads. Furthermore, an acoustic barrier has been constructed to reduce noise in the city centre (Rotterdam Office for Sustainability and Climate Change, 2011). Such measures could have a mitigating effect on air pollution and can be implemented in sustainable ports to protect human health. Operation of large machinery, traffic and marine vessels can cause disturbance in the form of noise disturbance.

##### *Impact on social welfare*

As mentioned in chapter 2, a port may produce noise, which can be a potential health risk. Effects of noise pollution on human health include heart disease, sleep disturbance and annoyance (Passchier-Vermeer & Passchier, 2000). The welfare effect depends on the volume of the sounds and the exposure to humans. For example, people working and living in the area of the port will be mostly affected. The main effects of noise are health consequences. For example, noise can cause hearing impairment, hypertension, and annoyance and sleep disturbance. Economic (negative) benefits of health can be measured by take into account parameters including productivity loss and value of reduced quality of life. CE Delft estimated that the social costs of traffic noise in the European Union are more than 40 billion euro per year (CE Delft, 2007) Noise pollution can also affect mammals and birds, which can have an impact on welfare as well (see ecosystem service wild life and biodiversity).

## **5.4 Costs of port development**

The main costs in a port development project are investment costs including construction, acquisition and other capital costs of the facility. Furthermore, there are the owner/operator's costs for operation and maintenance of the facilities. Additional costs can be investments such as railroad connections, roads and the development of an industrial zone. We will give a description of the construction costs, maintenance and operation costs and we highlight costs of dredging to give an idea of the amount of money involved in this sector.

#### 5.4.1 Construction costs

Development projects can be roughly divided into two categories:

1. Building new port/terminal in a new location.
2. Construction a (major) extension of an existing port.

The costs we can also divide between these categories. The costs of a new port include usually, the construction of breakwaters, quay walls, quays for container berths, general cargo or dry bulk berths, development of facilities such as dry docks, harbour cranes, buildings and terminal trucks and dredging. Additional substantial costs are costs for land reclamation or acquisition. The costs of expansion of a port depend on the aim of the expansion and the location of the port. However, these costs frequently include land reclamation or acquisition costs, the construction of new quays and dredging (Guler, 2003).

A brief literature study showed that the costs of port expansion will be in between 20 million and 3 billion euro, while the costs of port construction vary 1 and 6 billion euros depending on the type of project, projected cargo load and scope of works (Port consultants Rotterdam, 2013; Gerbich, 2010; Port Everglades, 2014; USACE, 2012). This shows that there is ample money involved for the development and expansion of ports, which have to be recouped by operating the port.

#### 5.4.2 Maintenance and operation costs

Maintenance and operation costs are reoccurring costs. Operation costs or running costs include labour costs, fuel supply/utilities, costs of electricity, insurance, auditing, royalties and legal fees, security and safety care and other overheads (Bichou, 2014).

Maintenance costs can be divided in preventive and corrective maintenance. Preventative maintenance will normally be carried out on a regular programmed cycle, such repainting of metal structures, drain cleaning and dredging. Sometimes a more urgent or larger maintenance is necessary (Marcom working group 103, 2008). These costs vary largely between ports. For example, labour costs depend on the country, while the need of regular dredging depends on the sediment carried into the basin and the trapping efficiency of a port (Deltares, 2010a). To get an idea of the extent of maintenance and operation costs: The additional maintenance and operational costs of an expansion of the port of Canaveral (Florida, USA) are estimated at approximately 500.000 euro, which is approximately 3% of the investment costs (USACE, 2012).

#### 5.4.3 Dredging costs

Dredging is considered more and more as an important expenditure, because of the increasing size of ships. Therefore we have a better look into the costs of dredging. The costs depend on the nature (composition and quality) of the sediment to be dredged, the frequency, the wave regime and the quantity to be dredged as well as the mobilization costs of the equipment.

The lowest costs are associated to the dredging of clay, silt, fine and medium sand, followed by dredging or removing hard soil, grave soil, coarse soil and rock. The disparity between dredging clay, silt and sand and gravel, hard soil and rock exceeds a factor of four. However, hard soil and rock will not need to be dredged for maintenance.

There is a difference between dredging for maintenance and dredging for the construction or expansion of a port. The navigation centre of the US Army Corps of Engineers (2014) shows that the costs of dredging for maintenance is approximately 4 dollar/m<sup>3</sup><sup>4</sup>, while first time dredging is about 16 dollar/m<sup>3</sup>. This may be due to the fact that it is more extensive to dredge

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<sup>4</sup> In 2013

harder material, but while it is dredged there will be less maintenance necessary. The costs of dredging for construction comprises a larger part of dredging compact or hard materials, which is more expensive, while dredging for maintenance includes more dredging of softer sediments such as clay, silt and fine sand.

## 5.5 Economic rationale of port development

Section 5.4.1. shows that investors are prepared to spend lots of money in port construction or expansion. However, the economic rationale behind port developments depends on the benefits of the stakeholders participating in the investment of a port. However, for national governments the economic rationale will depend mainly on the effect on social welfare (Guler, 2003). To show the difference between these rationales, we present both the financial benefits of port developments as well as the social welfare effects. All the effects of port development that will affect social welfare can be found in table 5.1. This can be seen as the result of the SCBA.

### 5.5.1 Financial benefits

The financial benefits can be divided between direct benefits to the port operator/owner and benefits of the port facility for the port users. The most important effect of construction or expansion of a port is (increased) port activity. The direct benefit to the port of this increased activity is the financial return from cargo services from ships including berthing fees, fees charged per ton of cargo handled and fees charged to remain cargo in storage (longer than the free time period) (Guler, 2003). Additionally, there are various other rental options and charges related to increased port activity.

The improved handling and berthing facilities, larger capacity of a port and in case of a new port smaller distance to the hinterland, are the main effects of port development for the port users. The benefits to port users are mainly cost saving benefits arising from reduced operating expenses, reduced overall inland transport costs and reduced turn-round time. The reduced operating expenses arise from reduced ship's waiting time costs (less congestion), increase of productivity and in case of widen and deepen channels from the economy of scale of operating larger ships. The main benefit of operating larger ships is the reduction of transportation costs, for example transportation costs for a ship of 3000 deadweight tonnage<sup>5</sup> is approximately 70 dollar per deadweight tonnage, while for a ship of 17000 this decreases to 22 dollar per deadweight tonnage (Guler, 2003). Although the transportation costs decreased during the years, these economies of scale are still present (Hofstra University, 2015). The reduction of costs could result in an increase of the port's competitive position. However, for a country this is only relevant if a port competes with ports in different countries on the same traffic.

### 5.5.2 Effects on social welfare

Section 5.3.3 showed already part of the effects of port development on social welfare related to ecosystem services. However, there are more effects on social welfare.

The most important effect of a port is that more trade capacity is made available. However, this does not tell us the effect of a port on social welfare. The effect of construction or expansion of a port on the national welfare of a country differs from the financial benefits. For example, it makes no difference for national welfare whether port users pay charges to the new port or to another port within the country. In case of competing with ports in different countries development of a port make a difference for national welfare, but still not for total

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<sup>5</sup> measure of how much weight a ship is carrying or can safely carry.

welfare. Therefore, the inclusion of these benefits depends on the scope of the SCBA<sup>6</sup>. In this analysis we focus on overall social welfare.

#### *Cost savings*

Cost saving benefits for port users will have a positive effect on national welfare. This is because cost savings will either raise the profit of port users or reduce prices of goods for consumers. Therefore, reduced operating expenses, reduced overall inland transport costs, reduced costs due to economies of scale and reduced turn-round time will increase welfare and are therefore considered as overall benefits. In a situation without port development, transport has to be either channelled or transported with different modalities (modal shift). Depending on the transport mode this will be more expensive than transport over water. Development of a port will save these costs.

#### *Increasing employment*

Expansion or construction of a port will improve the employment in a region directly in the port region but also indirectly at business that are connected to port. More intensive use of the available ports will probably result in less additional employment as in a situation of port development. Therefore the development of a port will generally result in higher employment rates. An additional benefit of port construction is the increased attractiveness of the region for companies. The development of a port will also increase the attractiveness of the region due to a better network position. This will positively influence the social welfare of a country.

#### *Benefits from other objectives*

Besides the before mentioned benefits, a port can be beneficial for other reasons. For example, regional tensions between countries can be one of the reasons to aim for self-reliance. Furthermore, military and security considerations can contribute to the need for the development of a port. Another reason can be the economic development of an economically under developed region. However, the resulting benefits from this kind of objectives will vary largely between countries and regions, and are difficult to quantify without specific knowledge of the actual situation.

### 5.5.3 Results Social Cost Benefit Analysis

This chapter summarizes the social costs and benefits of port development. Table 1 shows the potential direction of the effects of port development and gives an indication of the welfare effect. For example, a port will probably reduce or slightly reduce water quality, which may increase health costs, negatively impact the profit of the tourist sector and so on. The financial effects that will not influence social welfare are not included in the table. The arrows give the potential direction of the effect. The direction range from a decrease (arrow down), to a slightly decrease (arrow partly down), stable situation (arrow directs to the left), slightly increase (arrow partly up) and an increase (arrow up).

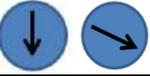
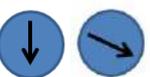
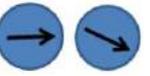
Recall the most important assumptions of this qualitative social cost benefit analysis.

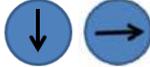
- The construction or expansion of a port will not influence worldwide shipping
- We consider the effect of port development on the changes in welfare for the whole society
- Welfare distribution and benefit transfers are not considered in the economic analysis. (However, they are part of the business case calculations for port development).

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<sup>6</sup> Assuming that sea traffic does not increase due to the construction/expansion of the port.

Table 5.1 Potential effects of port construction or expansion of a port: Indication of the physical effects and welfare effects and therefore play a role in achieving a no-impact port.

Benefits		Potential Effects	Indication of welfare effects	Literature
<b>Financial benefits</b>	Capacity of port		No change in fees from ships and cargoes. Reduced transport costs due to larger ships. Increase of employment rates Increase of economic attractiveness of the region, resulting e.g. in more turnover and higher employment rates	Guler, 2003
	Distance to hinterland		Reduced inland transport costs	Guler, 2003
	Quality of handling and berthing facilities		Reduced operation expenses	Guler, 2003
	<b>Ecosystem services</b>	Raw materials		Reduced costs extraction sand Reduced possibility use of sand for commercial use
Sea food			Reduced fish catch, price effects determines loss of profit.	Lipcius et al., 2008
Navigation/shipping			Increase costs dredging activities (no effect on social welfare)	Deltares, 2010
Flood protection			Slightly higher potential damage of floods	De Vriend & van Koningsveld, 2012
	Water quality and/or purification		Increase of health costs Slightly decrease profit tourist sector Small decrease fish catch, price effects determine loss of profit.	Hiranandi, 2012; Howarth et al., 2000; NOAA: Howarth et al., 2000

	Erosion and sedimentation regulation		Increase costs dredging activities Other welfare effects depend on location	Deltares, 2010a
	Climate regulation		Small increase in amount of CO <sub>2</sub> , which can be translated in the market price for carbon	Howarth et al., 2000; Lee et al., 2014
	Maintaining wildlife/biodiversity		Slightly decrease profit tourist sector Small decrease fish catch, price effects determines loss of profit. Small decrease in intrinsic value biodiversity	Bulleri & Chapman, 2010; Lipcius et al., 2008, Stronkhorst et al., 2003
	Recreational possibilities		Potentially small decrease profit tourist sector. Potentially small decrease value people attribute to the ecosystem.	Reese et al, 2010
<b>Other benefits</b>	Air quality		Small change in health costs, productivity loss, value of reduced quality of life. Change in amount of CO <sub>2</sub> , which can be translated in the market price for carbon.	Kampa & Castanas, 2008; Transport Research Knowledge, 2009
	Quiet environment (noise)		Small increase in health costs, productivity loss, value of reduced quality of life	Passchier-Vermeer & Passchier, 2000

The positive social welfare effects of a port are mainly reduced sea transport costs, reduced inland transport costs and reduced operational expenses, which may increase the profit of transport companies or reduce prices of goods benefiting consumers. Additionally, a port will improve employment and increase economical attractiveness of a region resulting in an overall positive welfare effect. Although there are many positive welfare effects, it may be possible that still a disproportionate part of the negative effects are transferred to the ecosystem. For example, a port can have such a large positive effect on total social welfare that it will overshadow any negative effects on social welfare. With the ecosystem service approach we obtained an insight in the potential negative social welfare effects of a port. The following effects will negatively affect social welfare due to port development. The large positive welfare effects of port development often outweigh any transfer of negative effects towards the ecosystem. Moreover as in many cases the stakeholders affected by the

negative effects are less vocal than port development authorities, or also partly stand to benefit from the port development.

The decrease in water quality negatively affects social welfare due to the impact on health, tourist industries and fisheries. Other effects depend largely on the type of ecosystem service present in a situation without a port. For example, the effect on most ecosystem services will be much larger if mangroves, corals, seagrass, salt marshes or beach and dunes (Barbier et al., 2011) are lost than if these ecosystems are not present. In that case the corresponding welfare effect will be much larger than stated in table 5.1. Some other ecosystem services are negatively affected by the construction of a port, but have a relatively small welfare effect. For example, although the ecosystem service navigation and shipping will decrease, the port will take measures to keep the necessary water depth resulting in no decrease of this ecosystem service. Since, the costs of this measure can be paid due to the presence of the port, the welfare effect is either zero or positive<sup>7</sup>. Another example is the effect on air quality. Our first intuition is that air quality will decrease due to the development of a port. However, development of a port will reduce the distance to the hinterland reducing inland transportation, and accordingly, the emissions of CO<sub>2</sub>, NO<sub>x</sub> and fine particles. The inland health effects of this transportation will be reduced. Note that there will be no social welfare effect if humans are not exposed to the emission. Another example is the potential negative effect on the fish population, probably negatively affecting fish catch. However, price effects potentially increase the profit of fishers, which can compensate the negative effect on consumers.

One of the questions of a SCBA is if this negative welfare effects outweigh the positive welfare effects and how these welfare effects are distributed over the different stakeholders. This study showed that this will depend on the location of the port (e.g. ecosystem services present) and the type of port development. However, we expect that only in limited cases the negative welfare effects of port development will outweigh the positive ones. Nevertheless, there are some concerns on distribution of effects over stakeholders and negative transfer effects to ecosystems. We recommend applying a case-specific study in a further analysis to test these findings.

#### Recommendations SCBA

To obtain a port with no-impact on the ecosystem, while positively affecting social welfare the impacts on ecosystem services need to be reduced. As illustrated in chapter 2 and 4 decreasing the impact on water quality, wild life/biodiversity and flood protection may potentially largely affect social welfare. However, the impacts depend largely on the location. The ecosystem service flood protection and air quality may be even positively affected by a no-impact port from a social welfare perspective. Eco-engineering solutions may increase flood protection<sup>8</sup>, while air quality may be increased by the combined effect of reduction of inland transportation and electric transportation at the port.

Like a traditional port, a no-impact port will benefit from the reduction of (sea) transport costs, reduced inland transport costs and reduced operational expenses. However, the investment costs may be higher than developing a traditional port. Here the finance viability comes into play (see chapter 5.5.4). In conclusion, a no-impact port development aims constructing a port, while limiting impacts on existing ecosystems and maximizing social welfare.

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<sup>7</sup> When including the positive effects on employment.

<sup>8</sup> Still depends on the location

Although we will not focus on the distribution of social welfare between stakeholders, we are aware of its importance. For example, a more equal distribution may be an important reason for stakeholders to support an initiative. We recommend including this in a further analysis.

In general, we would recommend applying a case-specific social cost benefit analysis, in which a situation without a port, a traditional port and a no-impact port are compared. This will give a more quantitative insight in the social and economic rationales of port development, which may be a reason for certain stakeholders to stimulate the development of no-impact ports.

## 5.6 Building the business case

### 5.6.1 Risks in port operations

Port operations (and therefore the port business) face several risks during the lifetime of the project. It may be possible that a no-impact design mitigates those risks from the start. This could have an effect on the business case. This effect could be both positive or negative. For the general situation a number of risks, the size of the risk (probability x costs) and the traditional measure are listed. Also the no-impact alternative and the impact of this alternative on the business case are shown (Table 5.2).

Table 5.2 The measures to reduce the effects of port operations in a no-impact port (Contribution on port operation: Blue=positive; yellow= medium and red= negative).

Risk	Probability	Costs	Measure	No-impact alternative	Impact alternative on business case
Lack of depth	High	High	Dredge	Create port where dredging is not needed.	Depends on costs of alternative location
Water pollution	High	High	Dredging of contaminated sediment	Allow natural banks to filter the water.	Positive
Rough seas preventing ships from entering port/mooring	Certain	High	Build breakwaters	Find an alternative location which is already protected	Depends on costs of alternative location
CO2 emissions are limited by regulations.	Limited	Depends on regulations.	Adapt when regulations are adopted.	Use sustainable energy wherever possible, generate energy	Depends on energy prices.

				locally.	
Future legislation on environmental standards	Medium	Depends on legislation	Adapt when legislation is adopted	Adapt during design phase	Negative
Clients demand 'no-impact' operations	Limited	High	Adapt when clients express demands	Adapt during design phase	Negative
Risks from climate change (storms, sea level rise)	Depending on project lifetime	Depends on lifetime and location	None	Construct port at a less exposed location, apply an 'adaptive management strategy'.	Negative

## 5.6.2 Financing no-impact port infrastructure: the public case

This paragraph identifies several aspects which may negatively impact the business case of a project, and therefore the financial viability. This paragraph focusses on public financing of publicly owned infrastructure.

The following assumptions are made:

- A no-impact port is considered: small, gradual improvements on the environmental impact of ports are not within the scope.
- The port is a landlord port: this is the predominant model in the western world. Basic infrastructure is owned by the port authority. The port authority is either part of the government or it is a state owned corporation.
- Only basic infrastructure is considered: basic infrastructure has most impact on the morphological environment of the port.
- Basic infrastructure is financed with debt: the port authority is a public entity and cannot finance by using equity. Debt is either sovereign debt or commercial debt, backed with a government guarantee.
- Revenues consist of port dues: port dues are paid by the shipping lines to the port authority.

The aspects relate to the several elements in the cash flow diagram and to the risk that those elements have different values than expected. The cash flow diagram and the several elements it consists of is shown in figure 5.4 Several characteristics of 'no-impact' infrastructure may negatively affect the business case of a project and increase the viability gap:

- The cost of constructing (#1) basic infrastructure is higher than in a 'traditional port'. This can happen because new, more expensive, technologies are being used;
- The cost of maintenance (#2) is higher than in a 'traditional port'. A reason for this may be that for example less aggressive, but less effective coatings are used on

underwater structures. On a positive note: maintenance costs may also be lower when less dredging is needed;

- Revenues are not high enough compared to a traditional port (#4). This could for example happen when the infrastructure is not able to receive the optimal ship sizes because depth in the port is not sufficient, due to restrictions on dredging.

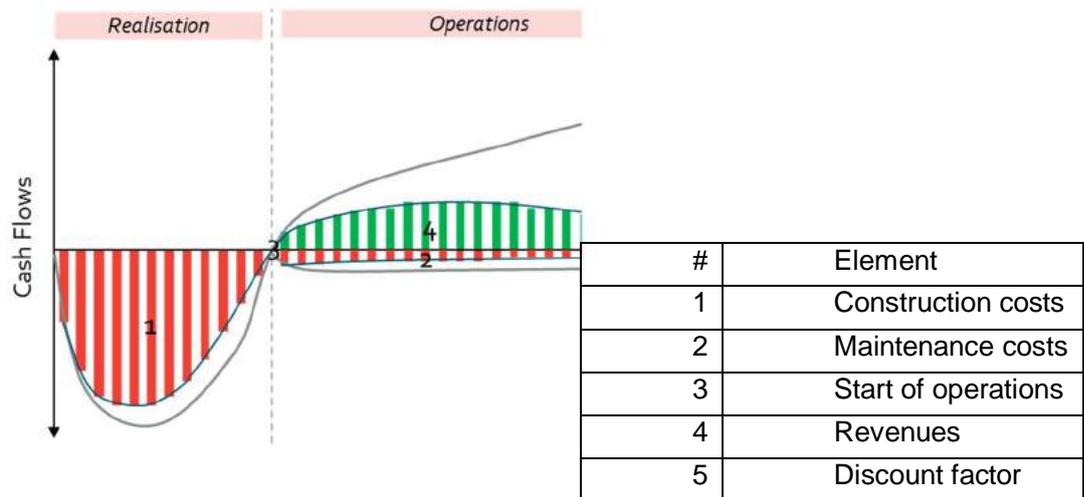


Figure 5.3 discounted cash flow during the lifetime of a project.

Source: Rebel.

Also the *risks* associated with the project may be higher than in a traditional port.

- The construction cost (#1) may turn out to be higher than expected because innovative methodologies may be used. This introduces the risk that halfway the project the innovative methodology turns out not to be working, in which case the constructor has to switch to a traditional building technique which incurs additional costs. Also the start of operations (#3) may move up in time when building does not go as planned.
- The risks associated with the maintenance costs (#2) are higher than in a traditional port when innovative methodologies are used for maintenance. This makes it difficult to predict the maintenance costs which creates uncertainty in the business case.

The possibilities for reducing costs and risks are limited. However, when the SCBA yields sufficiently positive results, the government may increase its subsidies. (Note that public ports operating in contestable markets are practically always subsidized). Furthermore, as long as the port has enough competitive advantages, consider to have sufficient competent staff trained vocationally and fundamental on the integrated port handling and design knowledge, the port dues can be raised to increase revenues. Innovative procurement strategies may limit the exposure to risks by allocating the risks differently. A variety of options exist in which the public party partners with the private sector to achieve this.

### 5.6.3 Financing no-impact port infrastructure: the private case

This paragraph focusses on privately financing privately owned port infrastructure. This gives more financing options, although the requirements for profitability will also be higher. The

private sector also requires a positive business case for project to be viable. The following assumptions are made:

- A no-impact port is considered: small, gradual improvements on the environmental impact of ports are not within the scope.
- The port is a private port: basic infrastructure is owned by the private port authority. The port authority is a corporation.
- Only basic infrastructure is considered: basic infrastructure has most impact on the morphological environment of the port.
- Basic infrastructure is partly financed with debt, and partly financed with equity. There is no direct state involvement, but state backed funds are an option.
- Revenues consist of port dues and handling fees: port dues and handling fees are paid by the shipping lines to the port authority.

The characteristics of no-impact port infrastructure may negatively affect the business case in the same way as when the infrastructure is publicly owned and financed. Construction and maintenance costs may be higher and revenues may be lower. Also the risks associated with those costs and revenues remain. In private financing the following aspect also play a role:

- The financiers (banks, investors) and equity-providers are assumed to look for the highest returns on their investments and may refrain from investing in the project because other investment-opportunities exist to them which offer higher returns. In the cash flow diagram (figure 5.3) this means the discount factor increases and the value of the project to the investor decreases (#5).

Several instruments exist to increase the attractiveness of the project for financiers and equity-providers.

- Government can support the project by providing fiscal stimuli or even subsidies;
- Equity, or commercial loans, can be leveraged with debt provided by a government backed fund or a development bank. This will increase the return on equity or can reduce the risk on commercial loans;
- Risks can be transferred to other parties, such as the government.
- Training sufficient competent staff and the integrated port handling

Even when the project is financially viable it may still be difficult to attract financing. This problem particular arises in those regions of the world where privately run ports are an option worth considering. Attracting financing is hampered by unfounded perception of risks or regulatory risks. Especially in developing countries perceived governance weaknesses may have a further negative effect on the availability of capital. This effect gets stronger when government intervention was initially needed to close the business case.

#### 5.6.4 Opportunities

For any specific case conclusions may only be drawn after having studied the particular situation. For the general theoretical situation, the paragraphs on port financing describe how the business cases of no-impact ports may be negatively impacted compared to a traditional port. It assumed here that no-impact ports are more expensive to build and operate. This is a valid assumption because if costs of no-impact ports would be lower we would already see

ports with those characteristics. Opportunities for a no-impact port arise when 'green' interests and 'business' interests overlap. This is when ports can be built on a location where changing of the environment is not necessary because the favourable location offers a 'natural' port. After all, when construction costs are minimal and throughput will be high enough the business case easily becomes positive, while the lack of basic infrastructure is reducing impact.

In other cases a port having no impact will cost more money than a traditional port. When, instead of striving for a no-impact port and avoid impact altogether the objective would be to *minimize* impact, other opportunities come forward. These will be different for every port as every port is unique. Ports operate within an environment where they need to find a balance between the interests of several different parties (including the government) and the economic needs of its hinterland. When looking for opportunities it is important to figure out what those interests are and what drives and motivates decision makers. Policies which minimize impact could be driven by regulation, corporate social responsibility or cost reduction. Finding drivers creates the need to map all the stakeholders. Sometimes stakeholder interests turn out to be aligned in some way which creates opportunities. A viable business case for *specific* measures allows to close the deal and implement those measures, serving all of the interests.

## 5.7 Conclusion SCBA and financial analysis

This chapter has outlined the general principles that are used to determine welfare effects of port development. These principles illustrate how possible negative effects to the coastal (eco)system can be translated to welfare effects, which has been done through the concept of ecosystem services. While port development will contribute to general increase of welfare, these principles illustrate the potential transfer of negative effects of traditional port development to the existing coastal system and possible existing economic stakeholders of the coastal system, like coastal fisheries, sediment mining or local inhabitants.

However, in order to be able to finance the development of a port, the port development should have a positive business case. When the port is publicly owned and financed, the government can subsidize development to achieve this. In case of private funding, without adequate returns on investment, or large or unknown risks associated with the port development, it will not be possible to attract financing for the port development.

The proposed no-impact port takes negative impacts on the environment and stakeholders in consideration. Developing a no-impact port with ecosystem based management approach is probably more expensive to build and operate than a traditional port. Governments and regulators have the opportunity to facilitate a conducive framework for 'no-impact' port infrastructure development through laws and regulations and financial instruments (subsidies, taxes, and guarantees on uncertainty). When port operators are incentive to develop 'no-impact' ports, the involvement of the private sector (through public private partnerships) can contribute significantly to reaching innovative solutions. Adequate and fair distribution of welfare is in principle the role of the government, as is the shared responsibility of sustainable economic development. No-impact port development can be stimulated through 'positive branding', conditionality of loans from finance institutions or active cooperation between governments and public private parties.



## 6 Application of optimal insight into future planning and no-impact port development

### 6.1 Summarized conclusions of chapters 2 to 5

In the previous chapters, the main factors of port development have been discussed. Overall conclusions of the previous chapters will be summarized in this paragraph. These findings can next be evaluated and integrated with the aim to address the most important factors of developing a no impact port (6.2). Furthermore, summarized conclusions of different chapters will serve as an input to create an overview table that summarizes the most important factors of port development and no-impact solutions (6.3). Finally, current limitations and knowledge gaps that are preventing the development of a no impact port will be discussed.

### 6.2 Coastal ecosystem factors of port development

In this study, we conclude that the potential impacts of port development on the coastal ecosystem is case specific, depending on the vulnerability of the system to different impacts and mitigating measures. The largest risks and opportunities for the no-impact port development lie in the morphology of the system. Disturbance of entire habitats with important functions will harm ecosystem functioning and degrade the ecosystem. In the no-impact port this harm should be avoided. Whether a sustainable port could potentially have impact on the coastal ecosystem, the state of the current coastal ecosystem, and the environmental requirements of physical, chemical and biotic conditions, should be assessed with indicators. The environmental indicators provide information about the current condition of the environment. This information can help port environmental managers to better recognise the potential impacts of the port authority's activities, products or services that may interact with the environment, and consequently, assist in the planning and implementation of environmental performance evaluation. It is required to monitor the indicators for the assessment of ecosystem functioning, such as the abundance of key species for the system and nutrient levels. Information on current biodiversity, hydrodynamics, key species and their requirements are for example necessary to gain more insight into the functioning and important requirements of the relevant coastal ecosystem. To avoid habitat loss, erosion or sedimentation of the port area, the environmental and biotic aspects of ecosystem functioning for different location choice and/or design should be assessed. To reduce the impacts on the environment (water- and air pollution, noise, alien species), a no-impact port should be developed together with stakeholder and regulators in alternative ways. Ecosystem based management will be the desired management approach in no-impact port development. It could also be included in the design of the port: choosing for eco-engineering solutions, deciding upon a location that requires the least adjustments to the natural system and taking functioning of important habitats into account.

#### **Morphological factors of no-impact port development**

As we have discussed in this study, port operations, design and location are interlinked. To co-create knowledge on the meaning of no-impact port, all these factors must be combined to develop the optimum port or port expansion. The dominant factors for developing a no-impact port are the location specific characteristics that should be taken into account in the design and operational plans. Erosion and sedimentation processes in the entrance channels and port basins influence the port efficiency, and provide a major economic reason to make alternative port designs or other mitigating measures to reduce the impact on coastline and environment. Port constructions on locations with larger natural depth (e.g. offshore ports) in

combination with innovative mooring techniques can reduce impacts caused by wave protective structures. From a no-impact ecosystem approach, it would be desirable if the location choice would be part of the design process, since the design and location choice are closely connected and have implications for the port operational management. This should be studied further, since it is beyond the scope of the present exploratory study.

### **Governance factors of port development**

In our study, we considered several port models that all allow for the development of sustainable port models, which are also useful as a no-impact port model. In the 'public service port/tool port' and the 'landlord port', public sector involvement allows for relatively easy implementation of 'green standards' as long as required funds (subsidies) are made available. However, the public sector have to deal with enforcing port management, policy making and governance in a sustainable way. When developing the no-impact port, the different stakeholders need to be involved and the private developments need to be steered by changing rules and regulations. In general, no-impact port development can be realised through cooperation between governments and stakeholders to require a financially viable project with a positive business case. The outcome of the stakeholders discussion process and the selection of indicators result in an integration of sustainability indicators for people, planet and profit. The 'governance' as such, does not prevent the development of green ports. However, we need to consider that 'no-impact ports' generate 'green benefits', which largely do not go to the port itself but to the society as a whole. The port benefits from this as well, profiting of increased public acceptance. The public private partnership contracts can be used to direct risks of no-impact port development towards the public sector. Privately funded ports offer opportunities for the no-impact port development without additional government spending.

However, a strong government is of importance to promote an ecosystem-based management approach and set the boundaries within which developments can take place for private investment innovations in a no-impact port.

### **Socio-economic factors of port development**

The no-impact port takes the negative impacts on both the environment and the stakeholders into consideration. Governments and regulators facilitate for 'no-impact' port infrastructure development with laws and regulation and financial instruments (subsidies, taxes, and guarantees on uncertainty). A no-impact port is probably more expensive to build and operate than a traditional port. This is a valid assumption because if costs of no-impact ports would be lower, there would already be ports with those characteristics. Ports operate within an environment where they need to find a balance between the interests of several different parties (including the government) and the economic needs of its hinterland. With the corporate social responsible policy of port authorities, some ports are reporting about a number of indicators that cover economic and social issues. When looking for opportunities, it is important to figure out what those interests are and what drives and motivates decision makers. A business case of a no-impact port easily becomes positive if the construction costs are minimal and throughput is high enough. The no-impact port development can be economically stimulated through positive branding, conditionality of loans from finance institutions or active cooperation between governments and the private sector. Moreover, additional ecosystem services should be identified that contribute to the business case. A viable business case for *specific* measures allows to close the deal and implement those measures, serving all of the interests.

### 6.3 Integration of conclusions: finding the crucial factors

There are a number of important findings with respect to the different disciplines of each chapter, that require to be integrated and evaluated for their importance in a no-impact port with an ecosystem-based approach. These findings include the importance of a port location, the interlinkage of different disciplines, and the importance of governmental, political and financial considerations.

#### 6.2.1 Port location

In order to integrate the findings of port development from different disciplines, we have tried to find the factor that links the different disciplines.

Evaluation of port development by different disciplines has found that the location of the port is a crucial factor that links the different disciplines. Each of these disciplines has a requirement for the location of the port:

- Ecological criteria: the location should not contain any ecosystem functions that may be disturbed or destroyed and the current morphology needs to facilitate few adjustments to the system (chapter 2);
- Morphological criteria: coastal (hydro)-morphology of a location needs to facilitate a port (chapter 3);
- Governmental criteria: the government of a location needs to be willing and relevant legislation needs to be in place (chapter 4);
- Socio-economic criteria: a port needs to be required at a location and there needs to be a market (chapter 5);

No-impact port development and stimulation of welfare and the protection of ecosystem services can be realised through active cooperation between PPP to require a financially positive business case. Furthermore, the location of port development often depends on governance factors as well. Port locations can differ in their morphology based on the natural system. Thus, the choice of a certain location stands in direct relation to certain necessary adjustments to the natural morphological system. For example, required depth and a proper connection with the hinterland are prerequisites in optimizing the ports' location and design to secure proper functioning of the harbour. In relation to the coastal ecosystem, the most optimal situation is the situation where there is as little as possible or no impact on the morphology, chemistry and biology.. Thus, port development in locations where many adjustments to the coastal morphology are applied, are usually least favourable for ecosystem functioning. Ecosystem functioning directly relates to many ecosystem services the coastal ecosystem offers for human benefit. Therefore, in order to strive for an ecosystem based management approach in port development, location is a crucial aspect.

In traditional port management, the location is often the starting point of port development and less of a variable taken into account to achieve no-impact. Furthermore, morphology is often considered more in a reactive way depending on the location and the required depth and protection for the functioning of the port. Therefore, morphology plays less of a role in optimisation in traditional ports with respect to taking the ecosystem into account. Furthermore, ecosystem services are not thought to play a significant role in traditional port design. As a result, a comparison between important disciplines of a traditional port and a no-impact port are described in figure 6.1.

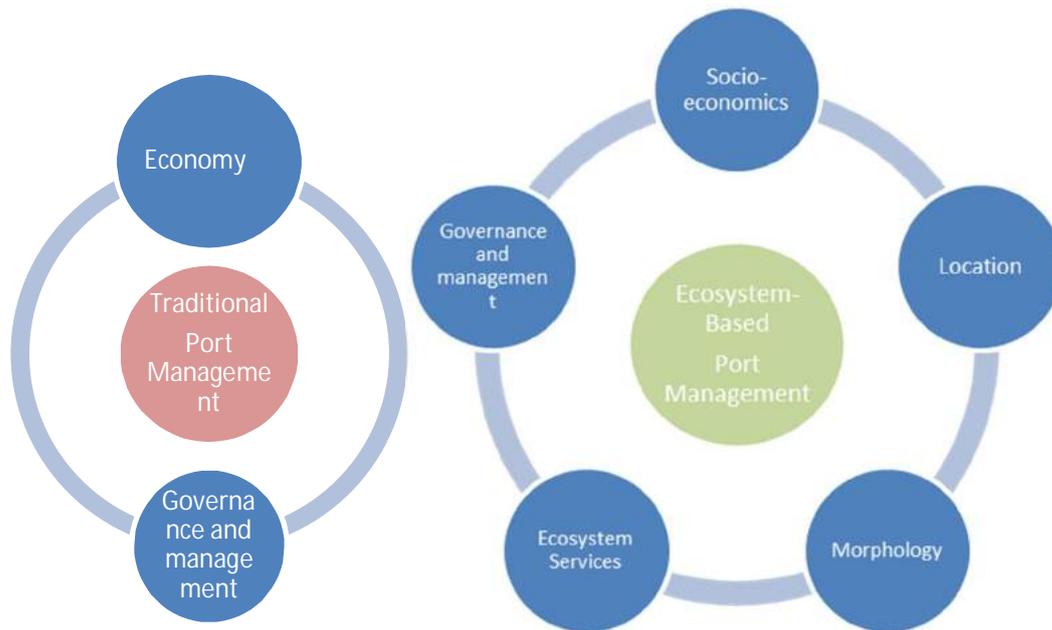


Figure 6.1 Important disciplines of port development in both a traditional port (A) and a no-impact port (B) (Deltares, 2015).

### 6.3.1 Interlinking different disciplines and factors of no impact-port development

In addition to the importance of port location, it was found that different disciplines are strongly interlinked and an optimized approach for all disciplines (figure 6.1) is essential.

From a governmental point of view, rules and regulations could be changed to influence private developments. Whether or not there will be investments from a socio-economic point of view depends on the risks of the project and the type of port model.

Risks should be allocated to the party that is best able to mitigate them. Subsidies from the government could be a way to do this. A reason for the government to provide these subsidies could be a positive effect on welfare, ecological protection and optimisation of ecosystem services.

In order to provide these ecosystem services, the ecosystem should remain intact. A way to promote the creation of new habitats and use their functions for ecosystem services could be through Building with Nature. These Building with Nature solutions need to be based on habitats that occur naturally in the specific coastal system and should not negatively interfere with present functions. An example of a Building with Nature solution is the creation of an artificial oyster reef, which structures could contribute to both wave attenuation and which biota could contribute to water quality. Introducing Building with Nature solutions could create added value for nature and ecosystem services when these were not yet in place in the previous coastal area. The right environmental conditions such as morphology are required for the creation of new habitats. Morphology is an important aspect of port design. A system that requires less maintenance with respect to morphology and sediment would be optimal for the port design.

This would be optimal for ecology as well, since there would be fewer repeated morphological impacts. An example for this could be a port at a location where a larger natural depth requires less dredging. The port layout could further be defined to have the least impact and

prevent erosion and sedimentation. Further prevention of erosion and sedimentation could for example be due to working with natural structures along the foreshore of the coast, as has been shown in several pilot projects of Building with Nature (De Vriend & Van Koningsveld, 2012). These structures could enhance flood protection services.

Investment in such innovations requires subsidies to bridge the viability gap between a positive SCBA and a negative business case. Therefore, public private partnership contracts can be used to direct these risks towards the public sector. Thus optimal governmental and political considerations are a prerequisite for a no-impact port that are very strongly interrelated with the location and the type of port that will eventually be developed.

### 6.3.2 The importance of governmental, finance and political considerations

Finally, governmental finance and political considerations were found to be important to achieve no-impact port development. In the end, the decision to build a port is based on whether or not it economically and financially makes sense to do so. Lower costs and higher benefits increase the chances of a port to be built. Things get difficult when a no-impact port requires higher investments than a traditional port or benefits are lower. This may for example happen when a building method is chosen which has less impact but is more costly. Or more connecting infrastructure has to be built, because the no-impact location is further away from the markets. Benefits may be lower when for example the 'natural' depth of a port is not deep enough to serve optimal ship sizes, while dredging would impact the ecosystem in an unacceptable way. This report has considered port governance models and touched upon some elements of financing 'no-impact ports' where a situation like this occurs.

This report elaborates on 'public' and 'private' port governance and corresponding finance. Both of those governance models allow for the development of no-impact port models but offer different opportunities. 'Public' governance models where both the benefits of the economic function of the port as the (avoided) costs of sustainable ports' are borne by society as a whole offer chances because a (public) discussion can be held on the distribution of those costs and benefits. This may result in higher subsidies than usual to enable no-impact port development.

Privately funded ports offer opportunities to develop alternative ports without additional government spending. A strong regulator (e.g. a strong government) is a requirement though to set the constraints within which port developments can take place, otherwise there is only very limited incentive for the private operator to develop a no impact port in the first place. To make privately funded no-impact ports financially viable, debt provided by International Financial Institutions such as the World Bank supporting 'green growth' may play a role.

Regardless of what governance model is used and what form of funding is required the chances of acquiring financing increase when the risks are well known and properly allocated. From the point of view of financial viability, (financial) risk management should therefore be an integral part of every design process for an alternative, 'no-impact port'.

## 6.4 Can no-impact port solutions be implemented for sustainable port development?

The conclusions and integration of the chapters 6.1 and 6.2 have been used to create an overview of the factors of port development for each discipline as presented in table 6.1. The impact of these factors in traditional port development and proposed solutions for a no-impact

port have been described. An artist impression of ‘traditional’ port development and no impact port development is shown in Figure 6.2.

Table 6.1: Impacts of factors and possible solutions in traditional port development and no-impact port development, based on analyses in the previous chapters.

<b>Coastal ecosystem factors of port development</b>	<b>Impact of factors in traditional port</b>	<b>No-impact port solutions</b>
Habitat loss due to construction	Loss of functions and negative for biodiversity	Avoidance through different location choice and/or design. If impossible: Building for Nature rehabilitation
Dredging activities	Loss of habitat, disruption of the seafloor, turbulence and coastal erosion	Avoidance through different location choice and/or design. If impossible: Promote salt marsh development, sustainable regulation, sustainable design. Rehabilitation
Water pollution	Algal blooms, changes in community structure	Regulation, Building with Nature
Noise pollution	Negative impact on marine mammals and possibly fishes	Switch to electric transport and noise regulation in ports
Air pollution	Ocean acidification effects	Regulation, innovation
Contaminated sediment	Toxic effects on biota	Regulation, re-use, sustainable disposal
Potential introduction of alien species	Impacts on community structure	Regulation, ballast water treatment, IMO
<b>Morphological factors of port development</b>	<b>Impact of factors in traditional port</b>	<b>No-impact port solutions</b>
Sedimentation in entrance channels and port basins	Dredging is required	Explore alternative port designs or other mitigating measures to minimise siltation in ports and entrance channels
Ports can interrupt alongshore sediment transports	Erosion and sedimentation in the area adjacent to a port	The port layout and port location could be defined such that impacts are at least minimised or possibly even avoided
Required depth for ships in ports	(Sandy/silt) shallow coastal zones require construction of entrance channels and port basins via dredging works	When possible a location with larger depth naturally available could get preference over other locations
<b>Governance factors of port development</b>	<b>Impact of factors in traditional port</b>	<b>No-impact port solutions</b>
Does the port give access to markets?	This largely defines the location.	In case an ideal sustainable port location is further away from markets, mitigate this by fast and reliable connecting infrastructure.
Are investments public or private?	Public investments require positive SCBA's and may involve subsidies to bridge the viability gap, private investments require positive business cases.	For public investments the viability gap <i>may</i> increase: more subsidies are needed. Private business cases <i>may</i> become negative: cheap or soft loans (IFI's) may be an option to make the business case positive again. PPP contracts can be used to

		direct risks (of no-impact port development) towards the public sector.
What rules and regulations are in place to steer private development?	The impact of private developments is constrained by rules and regulations.	Influence private development by changing rules and regulations.
What direct stakeholders are involved?	Only public parties or a mix of public and private parties.	When developing a no-impact port, involve the different stakeholders and understand their interests.
Existence of important externalities through port development	Stakeholders are sometimes (partially) compensated	Not only external stakeholders but also mitigation (or internalisation) of negative effects to other external factors are enforced through laws and regulations
<b>Socio-economic factors of port development</b>	<b>Impact of factors in traditional port</b>	<b>No-impact port solutions</b>
(Perceived) risk is an important factor in the decision whether or not to invest (both public as private).	In traditional ports risks are known.	Make sure all risks are known. If investments are required allocate the risks to the party which is best able to mitigate them.
Is the SCBA and the business case of the port positive?	Subsidies may be needed to bridge the viability gap between a positive SCBA and a negative business case.	Private initiatives to obtain (crowd) funding and subsidence



A)

Artist Impression





B)



Figure 6.2 Artist impression of a 'traditional' port development (A) and a 'no-impact' port development (B) as a way of achieving sustainable economic growth. During design and construction of the no-impact port, the choice for the port locations, governmental issues and ecosystem processes are taken into account as well as communication with all stakeholders. (Deltares, 2015; drawer Oomen)

Table 6.1 and figure 6.2 both create an overview of the possibilities of a no-impact port and possible solutions. However, there are some limitations and trade-offs that prevent all these solutions from being implemented.

Why the no-impact port does not exist yet.

#### 1. No public private partnership (PPP)

Currently, PPP is often missing. When PPP is missing, the government will not provide a capital subsidy in the form of a one-time grant, making it unattractive for private partners to invest. A government that does not operate through a partnership with one or more private sector companies, does not stimulate positive sustainable development. Since no-impact port development must be realised through close cooperation between public and private parties to be financially viable and this is not the case yet, a no-impact does not exist.

#### 2. Historic growth spurt in port activity

The greatest growth spurt in port activity and population followed during growth of international trade and large infrastructure development. In the past, cities and harbour started to expand on sandbanks of the river. The heart of the cities contained almost unhealthy industrial areas, however, slowly but steadily the traditional port grew into an economic port of importance. In the nineties, the policy changed to more liveable cities resulting in modern-style buildings and recreation facilities. Nowadays, the port and industrial area are managed and operated by the port authority, responsible for handling shipping traffic, and developing public infrastructure, existing port areas and new port sites. The main goal of the port authority is to strengthen the competitive position of the port in terms of size and quality. The integrated sustainable port development, say discussions about no-impact port, is not part of this process. Although ports are aiming at being more sustainable, developments are likely to apply to “the handicap of a head start”. Thus, since many ports have already been constructed in a traditional way without taking negative impacts into account, it is all the more difficult to adjust design and management compared to starting with an optimized design in the beginning of the development process.

#### 3. No financial sustainable investment, since economic model has positive business case.

The direct benefit to the port of increased trade activity is the financial return from cargo services from ships and fees charged to remain cargo in storage. The transportation costs decreased during the years, the reduction of costs resulted in an increase of the port's competitive position. Nearly no stimulus is made if a port competes with ports in different countries on their processes to succeed in a highly competitive sustainable global economy. The momentum for the no-impact port must be created in the stimulus phase by continuing to focus on jobs, growth in access to the market as well as long term sustainable economy.

#### 4. Importance of spatial regional port planning

In spatial regional planning, ports are considered in the light of their role in the region as multi-task centres, operating within combined transport chains, logistics systems and industrial and financial structures. Port industrialization and development reflects the varying attitudes and experiences associated with the industrialization of large urbanized maritime zones, particularly concerning port-city interrelationships and the role of ports in regional development. The concept of no-impact port spatial development planning should take into account not only all the port functions, but also spatial, economic and social connections, so the port – city – region.

#### 5. New innovations to strengthen port position

In this study, we have shown that ports take an increasingly important place in the competitive global economy (OECD 2012; World Bank 2012a; PIANC 2014a; 2014b). However, in the future innovative technical solutions, protection measurements of the environment and carbon reduction are needed to strengthen their position and, at the same time, to strengthen the image and attractiveness of the port areas. It is important that companies and ports become more sustainable and learn about the benefits of the concept of sustainable port and the no-impact port.

## 6.5 Knowledge gaps

### *Environmental:*

- An integrated approach to an ecosystem-based port development, that embraces the multiple perspectives of engineering, ecosystem services and governance, is currently lacking.
- From an ecosystem services perspective, knowledge gaps include the identification of relevant ecosystem services related to port development, the assessment of ecological and socio-economic impacts and the valuation of these ecosystem services in order to enable cost-benefit analyses in public and private business case studies.

### *Morphological:*

- It should be assessed if and how a port could potentially have no impact on the coastal ecosystem, while fulfilling its port functions, and so what such a port looks like, what its business case is and how it interacts with its environment.
- From an engineering perspective, knowledge gaps include design principles of no-impact ports, exemplary sustainable port lay-outs and how to improve nautical and morphodynamic impacts.

### *Governmental:*

- From a governance perspective, knowledge gaps include direct stakeholder perspectives and their dynamics, societal or institutional boundaries and opportunities for more sustainable ports, and an approach of co-creation that enables implementation processes. Under what conditions will the trade-off be made in favour of a sustainable port rather than a traditional port .

### *Socio-economical*

- From an economic perspective, a financially feasible business case that financiers would be willing to invest in should be developed.



## 7 Conclusions

The scope of this Port of the Future report is to achieve a long term sustainable port or, opportunistic, the no-impact port development programme as an integral and interactive sustainable initiative. Knowledge must be developed to balance economic growth and welfare in combination with healthy ecosystems. There is a need for innovative solutions for sustainable no-impact port development which are in harmony with the ecosystem and robust or adaptable under change.

### **Main conclusions of Port of the Future :**

- In this study, we conclude that the potential impacts of no-impact port development on the coastal ecosystem will be case specific, depending on the vulnerability of the system to different impacts and mitigating measures. (Chapter 2);
- An assessment of the state of the current coastal ecosystem, ecological feedback and environmental requirements of physical, chemical and biotic aspects for ecosystem functioning is required, using indicators that cover economic, social and environmental issues to determine whether port development would have impact on the coastal ecosystem. (Chapters 2 and 6);
- Ecosystem services can be used to address the socio-economic effects of impacts on the coastal ecosystem. (Chapter 2, 5 and 6);
- A financially viable no-impact port may be more expensive to build and operate. (Chapter 5);
- The main economic incentive to make an alternative port design or take mitigating measures are the costs and efficiency associated with erosion and sedimentation processes into the entrance channels and port basins. (Chapters 2, 3, 5 and 6);
- The largest risks and opportunities for no-impact port development lies in the morphology of the system: the use of natural depths reduces the extent in which depth needs to be designed and maintained by dredging and hence habitats are less disturbed. (Chapter 3 and 6);
- Since the location of a no-impact port is crucial for different disciplines, it is desirable if the location choice is part of the design process, since these aspects are closely connected and could affect operational management. (Chapters 6);
- Different disciplines in the no-impact port development are interlinked and can therefore influence and enforce each other to reach a balanced environmental good status in line with economic growth. (Chapter 6);
- Ecosystem based management is a management approach that is relevant and required in no-impact port development. (Chapter 6);

- Co-creation of knowledge on multi-disciplines (ecology, morphology, governance and socio-economy) with all stakeholders is necessary to develop the optimum port or port expansion. (Chapter 6);
- In general, the no-impact port development can be realised through cooperation between PPP to require a financially viable project with a positive business case. (Chapter 6);

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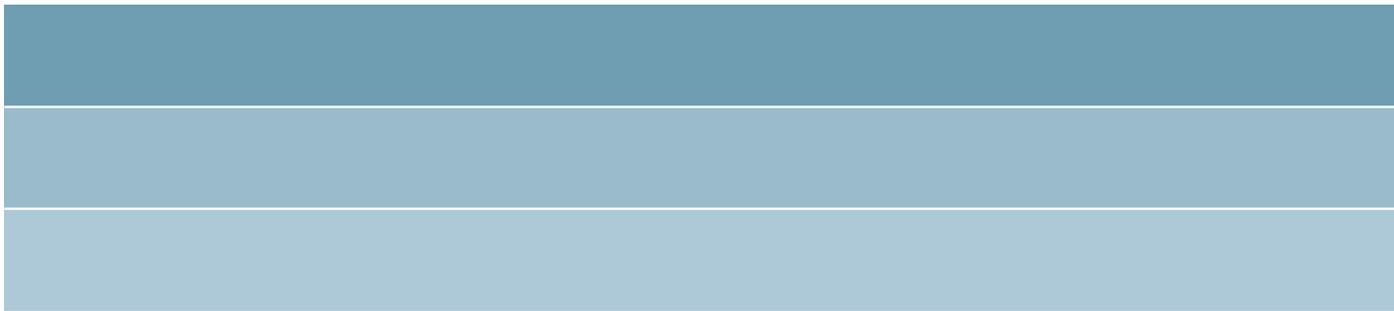
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