‘’CONNECTING MYANMAR’’ - TOWARDS A FRAMEWORK FOR A SUSTAINABLE AND STAKEHOLDER-INCLUSIVE DEEP SEA PORT DEVELOPMENT STRATEGY

A case study of ports in Myanmar

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A case study of ports in Myanmar

by

M. Oosterwegel BSc.

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EXECUTIVE SUMMARY

The Republic of the Union of Myanmar, formerly known as Burma, is a country in Southeast Asia with a population close to 60 million people, which suffers from underdeveloped infrastructure. One of the reasons for this underdevelopment were the economic sanctions imposed by the European Union and the United States. The sanctions led to isolation and restricted Myanmar undertaking trading and business activities limited mostly to neighbouring countries. With the change of government and restoration of democracy starting from 2011, and a new government since 2016, policy reforms are anticipated leading to large-scale economic development and growth. This growth is expected to result in rapidly increasing trade volumes which are mainly imported and exported by maritime transport. The maritime infrastructure however, needs upgrades: existing ports are mainly up-river, have limited draught and need continuous dredging. Myanmar needs a deep sea port to address the need to accommodate Post-Panamax vessels in the nearby future.

Problem and methodology

Currently, six deep sea port projects (Kyaukpyu, Pathein, Yangon, Thilawa, Mawlamyine, Dawei) are being planned in Myanmar, and their actual status is unclear. It is not known whether these sites are chosen based on rational and technical considerations or on geopolitical interests from the past. If these sites have been selected based on outdated political considerations rather than commercial, well-grounded and sustainable development, they may struggle to obtain finances and support. This problem exposes a broader research task of extending the site selection research from Myanmar to site selection in general. Especially in the past, port sites were often allocated by the government. However, nowadays many criteria and considerations for site selection exist, and a shift towards more sustainable approaches can be found worldwide. Guidelines and standards exist, but there is no proven framework for sustainable site selection which combines ecosystem-based management and a stakeholder-inclusive approach. However, because site selection is critical to port development and the long-term success and growth of a port, research into optimum and sustainable site selection is of significant value. These two problems jointly lead to the following research objective:

''Development of a strategy for deep sea port site selection and port development in Myanmar, by developing and applying a framework for sustainable site selection based on literature & desk study, a stakeholder-inclusive approach and a case study conducted in Myanmar. The strategy elaborates upon the optimum site selection (process), conceptual lay-outs and biggest challenges.''

This research will opt for a broad and large-scale approach. The objective is achieved by conducting a study of trends in sustainable port development, international guidelines on site selection, and consultation with experts which yields an initial framework for sustainable site selection. A case study and three months fieldwork based on interviews, desk study, site study and a multi-stakeholder workshop in Myanmar provide insights, data and stakeholder values for refinement of the initial framework in a bottom-up approach. The framework will be validated and applied on Myanmar. After application, a strategy for deep sea port site selection and port development in Myanmar will be formulated, which will include site ranking, development of conceptual lay-outs, and which brings into picture major challenges.

The main motivation for port development in Myanmar is to cater for the growing economy of Myanmar itself, which means serving its own hinterland. The country should focus on its own import and export. During the case study it became clear that Myanmar does not have its own policy with respect to site selection of its coastal ports. Two possible explanations for selecting sites of deep sea port development came forward:

- Neighbouring countries China, Thailand and India try to gain direct access to the Bay of Bengal for their land-locked regions, and plan, finance and construct ports focused on catering their own needs.
- In the final months of the military regime, the government decreed two laws to establish three special economic zones based on unknown considerations, which cannot be withdrawn.

Framework

Based on findings from the case study, a framework for sustainable site selection is developed and applied. The site selection framework consists of four phases: project initiation, requirements study, site identification/evaluation/ranking, and development of conceptual lay-outs. The core of the framework and this research is phase three, which concerns the actual site selection. This phase uses a two-step (filtering of a long list, evaluation of a short list) selection process with the following steps:

- Identification and longlisting of potential sites (both greenfield and brownfield).
- Determination of a filter technique: e.g. key criteria, distance to market, sustainability, a combination.
- Identification of showstoppers: political situation in a specific region, budget, ESIA.

- Evaluation by means of MCA, MAMCA, SWOT, BSC or CBA, based on project characteristics.
- Determination of stakeholders needs, values and priorities in a multi-stakeholder workshop.
- Identification of ecosystem services at a specific site and the interrelation with a port development.
- Ranking of sites based on stakeholder clustering, economic and political scenario's.

Key findings

Myanmar's coastline can roughly be divided into a North-Western stretch located in the Bay of Bengal, and a Southern stretch located in the Andaman Sea. In general, the Southern stretch is substantially better suited for deep sea port development because of the following reasons:

1. **Arakan mountain range:** These mountains stretch from Bangladesh towards Pathein and are densely forested, hardly accessible and act as a natural barrier between Central Myanmar and the Bay of Bengal.
2. **Corridor developments:** There are developed corridors in the south to Thailand and Vietnam, but little or no corridor (road/rail) developments planned in the North-Western states of Myanmar and the Arakans.
3. **Mild wave climate Andaman Sea:** The Andaman Sea is sheltered by the Andaman islands, causing a milder wave climate compared to the unsheltered Bay of Bengal, which is favorable for navigation.
4. **Complex political situation:** some areas have specific problems which would probably deter investors.

Following the site selection process, the first filter (filter based on four key criteria and a filter based on distance to market) resulted in a short list with Pathein, Yangon, Mawlamyine and Dawei, which corresponds to the sites at the Southern stretch. These four sites are evaluated in detail with a Multi-Actor Multi-Criteria Analysis. Depending on the priority given to various criteria, the following rankings are obtained:

- The environmental cluster: 1. Mawlamyine, 2. Yangon & Pathein, 3. Dawei
- The social/political cluster: 1. Yangon, 2. Mawlamyine, 3. Pathein, 4. Dawei
- The economic cluster: 1. Mawlamyine, 2. Yangon, 3. Pathein, 4. Dawei
- The cost-based cluster: 1. Mawlamyine, 2. Pathein, 3. Yangon, 4. Dawei

Yangon seems like a logical choice for deep sea port development, as it is the economic center of the country with the best hinterland connectivity. In principle, Yangon should have been filtered out in the first filter in based on its small water depths, but Yangon is kept in the site selection process to show that it is not the most optimum site for deep sea port development despite pressure and insights from many Myanmar stakeholders, because of the following physical restraints:

- From the city center towards the Yangon river mouth, maximum water depths of 10 m are available.
- Offshore from the river mouth, depths of 14 m exist only after 100 km and further.
- Outside the Yangon river mouth, large sedimentation problems arise (accretion of ± 500 m land/year).
- Soil in the Yangon river (mouth) consists mainly of mixed sand and mud, which cause large settlements.

Constructing the deep sea port in Yangon would result in an inflexible and unsustainable port which does not fit in the scope and way of thinking of this research. Omitting Yangon from the ranking leads to a new and clear site ranking which is the same for all four clusters: 1.) Mawlamyine (near Kalegauk Island), 2.) Pathein (Nga Yoke Kaung area), 3.) Dawei (SEZ). For the final site recommendation, reference is made to the two strategic objectives for maritime development as stated in the Transport Masterplan written by JICA and the MOTC:

- **Strategic objective (SO) 1:** Enhance port capacity of Yangon port including Thilawa area
- **Strategic objective (SO) 2:** Develop a deep sea port that can accommodate Post-Panamax vessels

Although Yangon is not suitable as deep sea port development site, it is a crucial port and must be part of the plan. Yangon and Thilawa port should maintain and strengthen their current activities (SO 1), and this appears best in combination with a deep sea port near Kalegauk Island (near Mawlamyine). This port will accommodate the large vessels (SO 2) and Yangon and its hinterland will be connected to it by sea, road, and rail. This combination of ports (deep sea port and feeder port) can for instance be found in Thailand, Cambodia and Vietnam. Kalegauk Island is not only suitable because of hydrographic and morphological considerations, it is also a good location due to a close and high-quality road connection with Thailand and the Greater Mekong Sub-region. Pathein and Dawei (ranked 2nd and 3rd in the site selection ranking) may serve as main gateway as well, although the analysis indicated more disadvantages. Additional research into these sites is required.

PREFACE

''Planning of future ports will probably never demonstrate a ''clean case'' of technology and economy because of considerations like inertia-effects associated with existing installations, national pride, military and political considerations.'' – Per Bruun (1989)

I read this statement at the beginning of my research and used it several times, because it perfectly describes this research in one sentence. Moreover, it describes the situation in Myanmar, and the goal of this research to demonstrate a ''clean case'' of technology, economy, and in addition sustainability. Before presenting this report and making important acknowledgements, I would like to express my strong hope and expectation that Myanmar finds peace and growing prosperity in the nearby future. The people of Myanmar are dedicated in achieving this, and they are the most helpful, friendly and dedicated people I have ever experienced. I hope that future port developments, in whichever way or whatever location, contribute to this.

This report is the result of ten months of thinking, talking, writing and discussion. It is written in partial fulfilment of the MSc. Hydraulic Engineering at Delft University of Technology and developed in close cooperation with the design and consultancy firm Arcadis, both in Rotterdam and in Yangon. My initial idea to focus on design considerations for offshore ports on artificial islands took shape during a conversation with prof. ir. Tiedo Vellinga, chairman of my graduation committee. Tiedo told me about Arcadis' activities in deep sea port developments in Myanmar and connected me with Ms. Tanya Huizer, project coordinator at the Arcadis office in Yangon. Luckily and accidentally, a few weeks earlier Tanya spoke with the Minister of Transport and Communications in Nay Pyi Taw, who asked for advice concerning site selection of a new deep sea port in Myanmar. In a subsequent meeting, dr. ir. Poonam Taneja and I started with shaping the research objective. This turned out to be the kick-off of my graduation project, with three incredible months of fieldwork in Myanmar.

I would like to thank Tiedo Vellinga for his help during the initiation phase of this research, and the informal and valuable feedback and discussions, Poonam Taneja who scientifically challenged me during meetings and always created time for feedback and brainstorming, and dr. ir. Martine Rutten for her feedback and Myanmar-flavored input. During this research, Arcadis greatly supported this research and I owe my thanks to my daily supervisor Chris Parkinson, as an expert on port planning and site selection. The weekly feedback greatly contributed to my thesis, and being a native English speaker, Chris was of great value in improving my English academic writing.

As part of this research, I had the opportunity to conduct three months of fieldwork for the case study in Yangon, Myanmar. I will never forget this experience and have to emphasize that the insights and knowledge I obtained during this period were of invaluable importance. Interacting with stakeholders and working right in the middle of the case study lifted this report to a higher level in my opinion. I owe special thanks to my supervisors in Myanmar Tanya Huizer and Johannes de Groot, two highly dedicated and professional persons. In addition, I would like to thank my fellow intern Marielle Chartier and colleague Zin Thaw Oo, for the wonderful office hours. Thank you all, for being great colleagues and great friends.

Then, I would like to thank all the many stakeholders in Myanmar for their advice in developing parameters and insights for this research, and people from Delft University of Technology and Arcadis, who assisted in validating the framework or in some other way.

Lastly, I should thank many individuals, friends and family who have not been mentioned here personally, in making this academic process a success. I could not have finished this study without your supports.

Michel Oosterwegel

Rotterdam, June 2018

LIST OF ABBREVIATIONS

- ADB: Asian Development Bank
- ASEAN: Association of South-East Asian Nations
- CITIC: China International Trust Investment Corporation
- CSIR: Council for Scientific and Industrial Research
- DICA: Directorate of Investments and Company Administration
- DMA: Department of Marine Administration
- DMH: Department of Meteorology and Hydrology
- DWIR: Directorate of Water Resources and Improvement of River Systems
- EU: European Union
- ICEM: International Centre for Environmental Management
- ICJ: International Commission of Jurists
- IWT: Inland Water Transport
- JICA: Japanese International Cooperation Agency
- MIP: Myanmar Industrial Port
- MITT: Myanmar International Terminals Thilawa
- MMU: Myanmar Maritime University
- MOC: Ministry of Construction
- MOGE: Myanmar Oil and Gas Enterprise
- MONREC: Ministry of Natural Resources and Environmental Conservation
- MOPF: Ministry of Planning and Finance
- MOTC: Ministry of Transport and Communications
- MPA: Myanmar Port Authority
- NEPS: National Engineering and Planning Services
- PIANC: Permanent International Commission for Navigation Congresses
- PIC: Pathein Industrial City
- TEEB: The Economics of Ecosystems and Biodiversity
- TWA: The Water Agency
- UNCTAD: United Nations Conference on Trade and Development
- UNEP: United Nations Environment Program
- YIP: Yangon International Port
- WB: World Bank

- APP: Adaptive Port Planning
- BSC Balanced Score Card
- BWN: Building With Nature
- CAPEX: Capital Expenditures
- CBA: Cost Benefit Analysis
- EBD: Ecosystem-Based Design
- EBM: Ecosystem-Based Management
- ES: Ecosystem Services
- ESF: Environmental & Social Framework
- ESIA: Environmental & Social Impact Assessment
- EWEC: East West Economic Corridor
- GDP: Gross Domestic Profit
- MAMCA: Multi-Actor Multi Criteria Analysis
- MCA: Multi-Criteria Analysis
- MCAP: Multi-Criteria Aggregation Procedure
- MCDA: Multi-Criteria Decision Aid
- MCDM: Multi-Criteria Decision Method
- MEA: Millennium Environmental Assessment
- OPEX: Operating Expenditures
- POF: Port of the Future
- SDG: Sustainable Development Goals
- SEZ: Special Economic Zone
- TBL: Triple Bottom Line
- TEU: Twenty-foot Equivalent Unit

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1 INTRODUCTION

1.1 Background – A shifting Myanmar

Myanmar, formerly known as Burma, is a country in south-east Asia with a population close to 60 million people. Myanmar suffers from underdevelopment in some sectors, e.g. infrastructure, and is categorized by the World Bank as low income economy. One of the reasons for the lack of development were the sanctions imposed by the US until 2016 and EU countries until 2012 (however EU sanctions were renewed in 2018). This led to isolation and restricted it to undertake trading activities limited mostly to neighboring countries. With the change of government and restoration of democracy, starting from 2011 and with a new government since 2016, policy reforms are anticipated leading to large-scale economic development and growth. These economic developments cause rapidly increasing trade volumes which are mainly imported and exported by maritime transport. Therefore, many maritime developments and upgrades of ports and waterways are needed and expected.

As JICA (2016) states, Myanmar is one of the relatively larger countries in south-east Asia, however its economic development has been delayed due to economic sanctions by foreign countries. Myanmar possesses a coastline of 2832 km and its strategic geographic location puts it at the heart of the fastest growing region in the global economy and in the middle of approximately 50% of the world's population, next to India and China which possess large industrial power and have strong consumption demand. This brings great development potential to Myanmar, and therefore the recent lifting of sanctions is likely to trigger rapid economic developments.

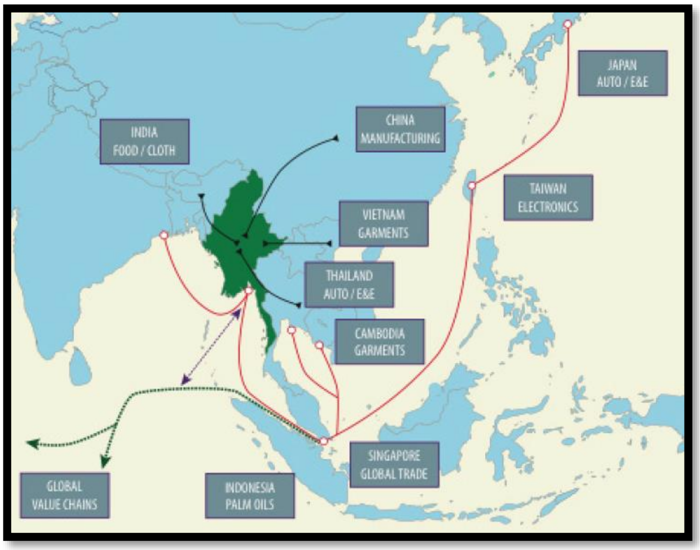


Figure 1: Strategic location of Myanmar (JICA, 2017)

During the old regime, investments in infrastructure were suspended. The (maritime) infrastructure is heavily outdated, existing ports are up rivers which have limited draught and need continuous dredging: there are no deep sea ports. Road and rail infrastructure is also limited and most villages can only be reached by inland water transport. Much of this water transport takes place on the Irrawady river, which ends in the vulnerable and unstable Irrawady delta. Myanmar works on improving the (maritime) infrastructure and is assisted by foreign parties to cope with the maintenance of existing waterways and development of new maritime infrastructure. As the Minister of Transport & Communications of the Republic of the Union of Myanmar, U Thant Sin Maung, stated to Arcadis:

''For topics like reducing costs for dredging, and deep sea port developments, I am not an expert and I need people like you (Arcadis) to help me.'' (Naypyitaw, 27th of April 2017)

Myanmar and The Netherlands, both with large and low lying deltas and large river systems, share many common challenges (Dutch Maritime Network, 2016). One of these challenges is port development, in which a large shift towards a more sustainable approach can be found worldwide. In sustainable port development, focus on profit in earlier years changes to a focus to include people, planet and profit. Two major new ways of thinking which try to incorporate perspectives of engineering, ecology, economy and governance in an integrated approach, trying to achieve sustainable port development and site selection, will be leading in this research . These ways of thinking are:

- Stakeholder inclusive approach
- Ecosystem-based management

A growing consensus recognizes 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 and lenders, particularly in East Asia, Africa and the EU, where sustainable strategies are at the heart of its blueprint for competitiveness (World Bank, 2012). Sustainable development should be included in the site selection process, at the very beginning of port development. However, an integrated approach of implementing specific sustainability approaches into deep sea port site selection is lacking until now.

1.2 Problem statement

The initial problem the thesis addresses originates from Arcadis, based on the needs of Myanmar, but gives rise to a broader problem which will be the subject of this research. The motivation for this research on port development and site selection can best be illustrated by a statement of Bruun (1989):

''Planning of future ports will probably never demonstrate a ''clean case'' of technology and economy because of considerations like inertia-effects associated with existing installations, national pride, military and political considerations''.

This research aims to demonstrate a ''clean case'' of technology, economy, and sustainability with respect to port development. Since the fall of the military regime, international trade is growing and Myanmar needs deep sea port(s) to address the need to accommodate large vessels in the nearby future. Ports in Myanmar share common problems, some of the ports are up river, all ports experience limited water depths in combination with frequent dredging, and port infrastructure is heavily outdated. Currently, four deep sea port projects are being planned, for all of which the actual status is unclear. The four sites are at Kyaukpyu, Ngayoke Bay, Kalegauk and Dawei, as can be seen in figure 2. Information about these projects is outdated, incomplete and originating from the former government.

It is not known whether the site selections of these ports are based on rational and technical considerations or on geopolitical interests from the past. The expectation is that the selection of current sites did not consider commercial, logical and sustainable development from a Myanmar wide perspective. If these sites have been selected based on outdated political considerations rather than commercial, well-grounded and sustainable development, they may struggle to obtain finance. This leads to the first problem statement:

- Lack of a clear methodology for deep sea port site selection and port development in Myanmar, and the associated impact on obtaining finance.

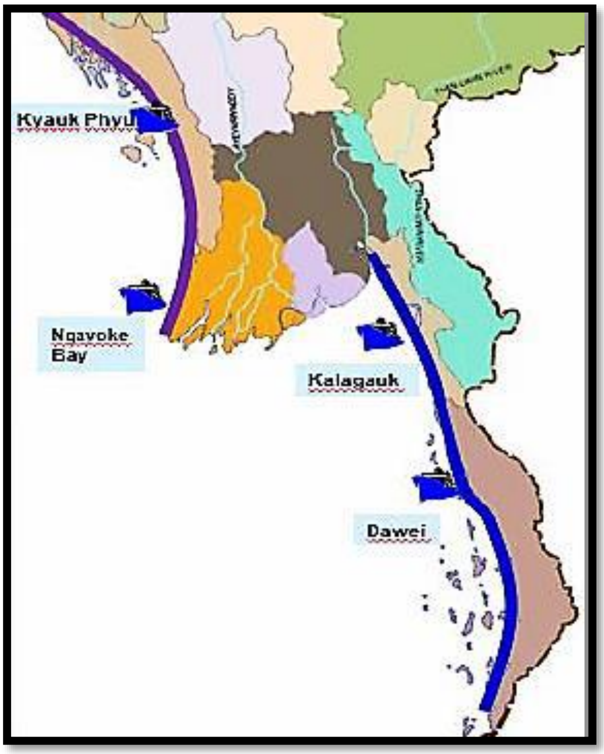


Figure 2: Current deep sea port developments (Dutch Maritime Network, 2016)

The problem as stated above is issued by Arcadis and will be the subject of a comprehensive case study. It exposes a broader research task of extending the site selection research from Myanmar to site selection in general. Because of the earlier mentioned shift towards more sustainable approaches in port development and site selection it is useful to investigate current trends and working practices, and provide insights on how well-considered, sustainable and technically sound site selection should be done. Especially because of the absence of a PIANC (Permanent International Association of Navigation Congresses) report on site selection at the time of this research (2017). A working group of PIANC is working on PIANC 185: Site Selection and Planning for New Ports and Specialist Marine Terminals on Greenfield Sites. This research can be an added value to this PIANC report.

Besides absence of a PIANC report on site selection, occurrence of site selection in books and literature is low. Especially in the past, port sites were often determined by politics. However, nowadays many more criteria and considerations for site selection exist. Guidelines and standards exist, but there is no proven framework for sustainable site selection in developing countries. However, because site selection is critical to initial port development and the longer term success and growth of ports, research into optimum and sustainable site selection is of significant potential value. This leads to the second problem statement:

- A framework which integrates a stakeholder-inclusive approach and the concept of ecosystem services, together with traditional and commercial site selection drivers is missing.

These two problem statements lead to the research objectives and questions in the following sections.

1.3 Research objectives & definitions

The research objective is twofold, and consists of a project specific research objective and a generic academic research objective. Following the book ‘Designing a Research Project’ by Verschuren & Doorewaard (2010), each research project mostly serves both a theoretical and a practical goal. In this case, the research project which was initially designed as a practice-oriented project, will contribute to the development of theoretical knowledge in this field. This will be called the ‘theoretical relevance’ of the research project. On the other hand, the practical relevance provides useful information which can be used in practice by the client and other stakeholders. **The main research objective** of this research can be formulated as follows:

> *The research objective concerns developing a strategy for deep sea port site selection and development in Myanmar, by developing and applying a framework for sustainable site selection based on literature & desk study, a stakeholder-inclusive approach and a case study conducted in Myanmar. The strategy elaborates on the optimum site selection (process), conceptual lay-out and biggest challenges.*

The theoretical relevance of the main research objective:

> *The theory-oriented research objective is the development and validation of a framework for sustainable site selection for a deep sea port, based on trends in sustainable port development and insights from a case study in Myanmar.*

The practical relevance of the main research objective:

> *The practice-oriented research objective is formulating a strategy for deep sea port site selection and development in Myanmar, by applying the framework, for optimum deep sea port site selection, conceptual port lay-outs for alternative locations, bringing into picture challenges, and business opportunities.*

Aiming for consistency in terminology starts with defining the most important and frequently used definitions. These definitions will be introduced in this section, and consistently used throughout this research:

- **Port:** for brevity, the word ‘port’ is used to indicate a deep sea port in this research, unless stated otherwise. A deep sea port is capable of handling Post-Panamax vessels, and is situated directly along the coastline.
- **Site:** any location along a coastline at which deep seaport development is possible and feasible.
- **Site selection:** the process of allocating a port to a specific site, based on site selection criteria.
- **Site selection criteria:** criteria based on which site selection takes place by valuing these criteria for alternative sites.
- **(Site selection) framework:** a schematic, step-wise depiction of the underlying process of site selection.
- **Initial framework:** the framework with site selection criteria and process steps derived from a literature and desk study.
- **Ecosystem services:** ecosystem services are the benefits people obtain from ecosystems. These services can be supporting (e.g. habitats), provisioning (e.g. food and fresh water), regulating (e.g. flood regulation) or cultural (e.g. recreational possibilities).
- **Ecosystem-based management:** using these ecosystem services in management of coastal ecosystems, is often called ecosystem-based management (EBM). EBM is aimed at conserving and sustaining ecosystem services to benefit current and future human generations.
- **Ecosystem-based design:** using the concept of Ecosystem Services in order to design a port (lay-out) such that the negative impacts of the port development on the Ecosystem Services are minimized and the positive impacts and opportunities of the port development on the Ecosystem Services are maximized.

1.4 Research framework

The research framework consists of a schematic representation of the research phases. The framework starts with the information sources for constructing a theoretical framework, after which the research objects are formulated. These objects are the phenomena under study. In the analysis of relations, confrontation of objects will be carried out to obtain the required results. These results help achieving the research objectives.

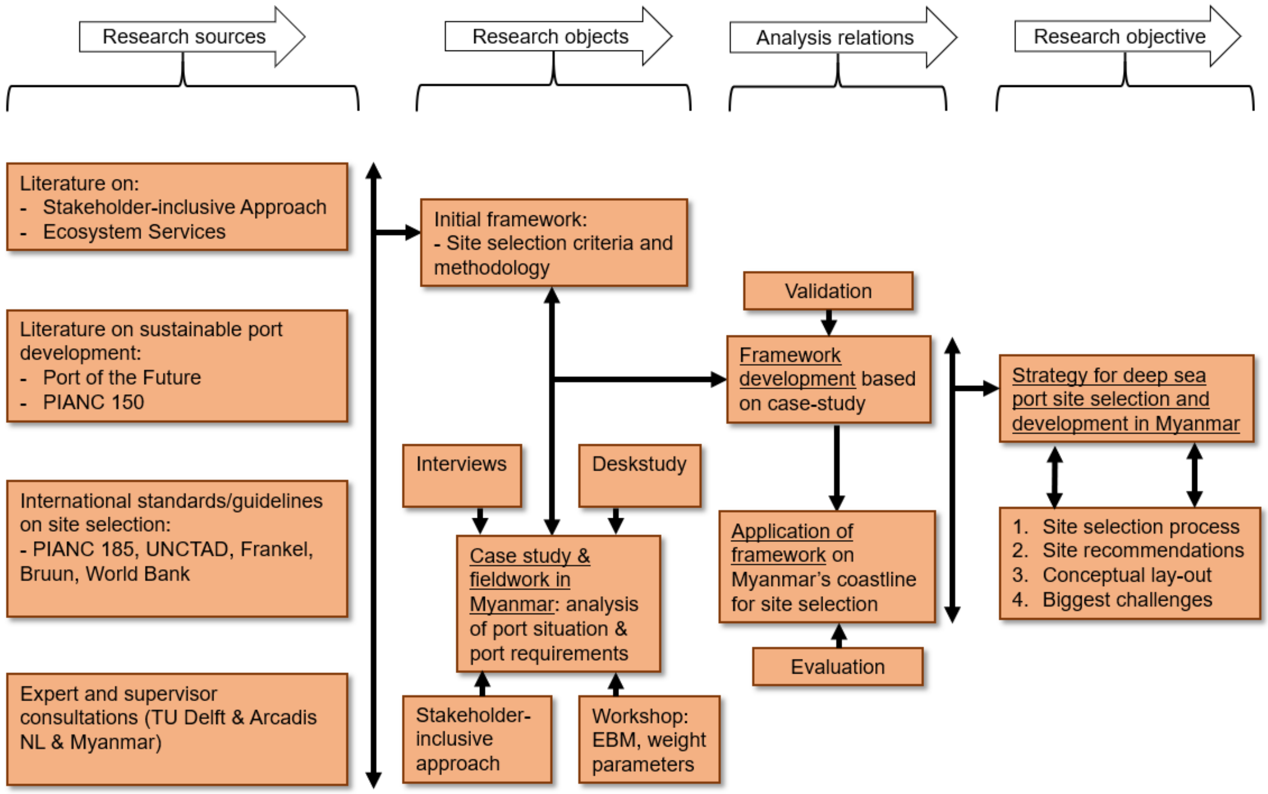


Figure 3: Research framework (source: author)

The research framework presented in Figure 3 can be phrased as follows: *'A study of trends in sustainable port development, international standards and guidelines on site selection, and consultation of experts and supervisors, yields an initial framework for sustainable site selection. A case study and three months of fieldwork based on interviews, desk study, a multi-stakeholder workshop and a stakeholder-inclusive approach in Myanmar will yield insights, data and stakeholder values for refinement of the initial framework in a bottom-up approach. The framework will be validated and applied on Myanmar. After application, a strategy for deep sea port site selection and development in Myanmar will be formulated, and will include site ranking, development of conceptual lay-outs, and brings into picture major challenges.'*

1.5 Research question

The main research question can be formulated as follows:

Which long-term deep sea port site selection and development strategy should Myanmar adopt to meet the growing demand for maritime shipping, that takes into account current trends in sustainable deep sea port development and site selection?

This main research question requires an exploratory research method, in which literature study, case studies and stakeholder consultations will be used to provide an answer. In order to answer the main question systematically, the following research steps will be followed:

1. Studying relevant criteria, methods and international standards and guidelines with respect to the site selection of deep sea ports.
2. Investigating current trends in sustainable port development and site selection.
3. Determination of the needs and stakeholder's values for deep sea port development in Myanmar.
4. Constructing an overview of current deep sea port developments in Myanmar.
5. Investigating considerations and methods for site selection of existing ports and current deep sea port developments in Myanmar.
6. Developing a framework for guidance during the site selection process.
7. Application of the site selection framework on the coastline of Myanmar.
8. Setting up alternative lay-outs for the selected sites taking into account sustainable design principles.

1.6 Methodology

According to Verschuren & Doorewaard (2010), a key decision within describing the methodology is the choice between breadth or depth. This research will opt for a broad and large-scale approach which enables generalization of the results, but will impose limits on the depth. The methodology can be divided in several main steps, corresponding with the structure of this report and the eight research steps. An overview of the methodology given for each chapter and research step is given in Table 1.

Table 1: Relation between chapters, methodology and research steps

Chapter	Methodology	Detailed method & working practice	Step
1.	Preparatory research	• Expert & supervisor consultations (TU & Arcadis) • Literature & desk study into research possibilities	-
2.	Literature & desk study	• Creation of initial site selection framework • Provide overview of related research and definitions	1 & 2
3.	Case study & fieldwork	• Assessment of port requirements for Myanmar • Provision of structure for data gathering	3, 4 & 5
4.	Case study & fieldwork	• Data gathering: interviews, desk study, workshop • Assessment of current deep sea port developments	3, 4 & 5
5	Framework development	• Development of framework in bottom-up approach • Validation of the proposed framework	6
6	Application of framework	• Application for Myanmar port site recommendation • Reporting of shortcomings and improvements	7
7.	Conceptual lay-out	• Setting up of conceptual lay-out of sea port site • Elaborate on the (sustainable) basic aspects	8
8.	Strategy definition	• Strategy includes recommendations for locations, selection process, lay-out, biggest challenges	Main question
9.	Discussion & evaluation	• Discussion of process, workshop, framework • Suggesting recommendations for further research	-

2 FRAMING THE RESEARCH

Site selection can be defined as the process of allocating a specific site or location for developments. The process of site selection can be carried out by means of political considerations, which often causes an absence of the full technical and economic site selection process in the full port master planning. This research aims at investigating the site selection process from a more technical, sustainable and logistical point-of-view. In literature, several books and guidelines describe aspects of site selection, however a generic and internationally accepted framework for site selection does not exist. This section aims at summarizing useful sources which will be used in setting up the initial framework for site selection, and at gaining insights into frequently used aspects and criteria for site selection in literature.

2.1 Site selection in literature

Site selection is a strategic, and a very fundamental and long-term decision for a company. In addition, site selection and site analysis occurs in a relatively early project phase. During this phase, the level of detail of the available information is relatively low. The professional involved in location strategies and site selection should be able to enhance his skills in applying evaluation methods with limited amount of detailed information. The growing importance of site selection is reflected in developments in specialized literature. As of today, four fundamental types of location theories can be distinguished (Glatte, 2015):

- Site selection theory: analyzes the reasons for the selection of a site
- Site effect theory: looks into the consequences of choosing the particular site
- Site development theory: analyzes the historic development of site structures
- Site design theory: analyzes the various options for designing the spatial distribution of sites.

Site selection theory focuses mostly on business administration and technical issues. Site design theory focuses on economic policy and macroeconomic issues. Site effect theory and site development theory cover all aspects mentioned above. Figure 4 shows different types of evaluation methods in location strategies. Some of these methods will be discussed in section 5.3.

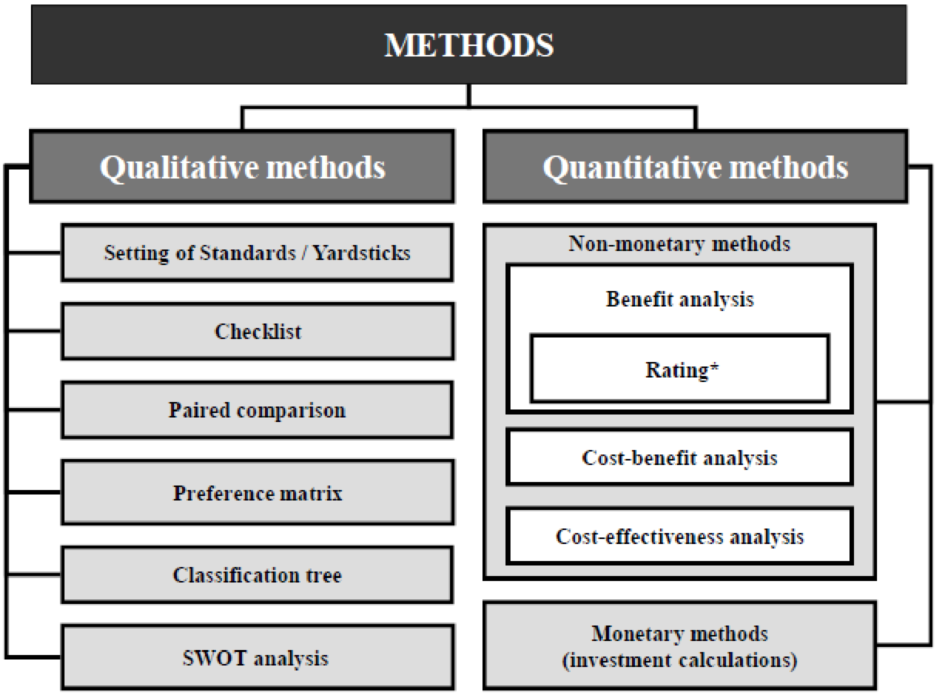


Figure 4: Evaluation methods used in location strategies (Glatte, 2015)

In site evaluation, a distinction should be made between site requirements and site conditions. The degree to which the condition of a site meets the site requirements is called relative site quality. The site requirements are the investment criteria for a company willing to establish a branch, while the site conditions are the actual conditions at the location in question (Glatte, 2015).

Information gathering is of great importance, however due to time and financial constrains during the selection process, a limit is put on the maximum amount of information. This applies both to the quantity and the quality of information available. In the first stages of site selection, information about a large number of sites must be obtained and analyzed in a short time. During progression of the selection process, the number of sites decreases while the depth of the information of the sites increases. Figure 5 shows this funneling of the number of sites and the available information, together with different possible stages in the site selection process.

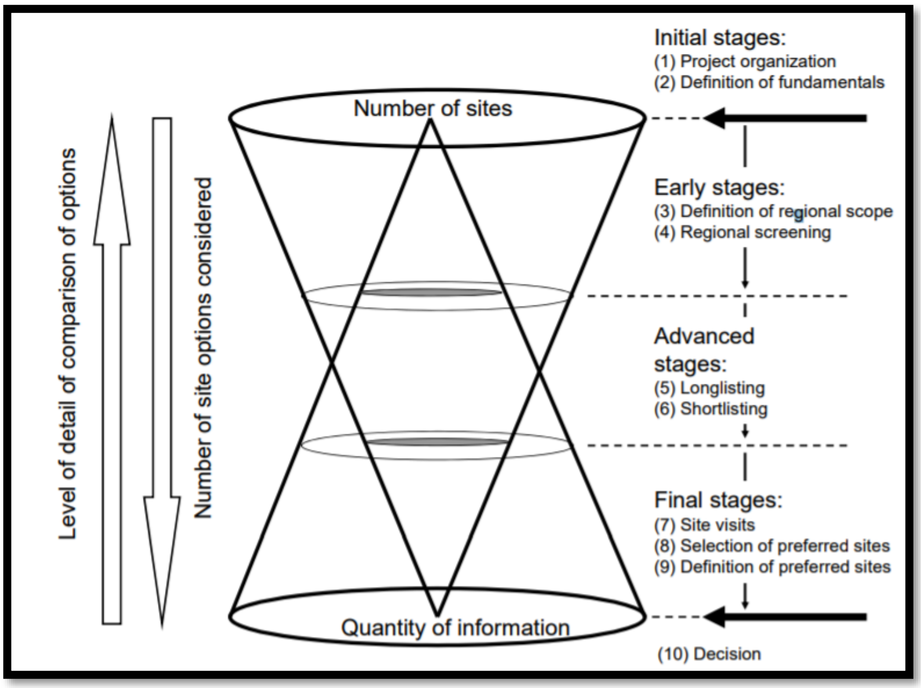


Figure 5: Funnel model on site selection (Glatte, 2015)

A well-known port planning book written by Frankel (1987) states that choosing the right location is important because of three aspects:

1. The total investment cost of site preparation varies widely among alternatives
2. Attractiveness to future port users may also vary widely among alternatives
3. Proximity to/from demand centers that the port is designed to serve and inland transport requirements

A location should be chosen by making a list of possible locations, after which a location is chosen considering: regional development policy, local conditions (infrastructure), labor availability, socio-economic conditions, and natural conditions suitable for port operation such as natural shelter, mild wave and wind climate and reasonable water depths. It is argued whether this site selection process is detailed enough, because many other criteria and considerations can be taken into account. Subsequently, according to Frankel (1987) a site should be chosen based on criteria as presented in Table 2. Frankel's list lacks the operating expenditures (OPEX), which is a key criterion for a country like Myanmar.

Table 2: Site selection criteria according to Frankel (1987)

Cost	**Local conditions**	**Environmental impact**
Cost of land	Wind, waves, climate	Public policy vs. private interest
Taxes	Underground conditions	Population
Site preparation	Access channel	Development of infrastructure
Site development	Inland traffic connections	Ecology (water, air, soil, ecology)
	Utility connections	Landscape
	Socio-economic conditions	

In 'Port Engineering' of Bruun (1989), the author provides his vision on a change in philosophy in which a port should call to the vessel instead of a vessel calling to the port. This is a first example of creating offshore ports in areas where large water depths already exist, instead of dredging large amounts at shallow areas, which is a new and innovative way of designing nowadays. Developing these deep draft terminals in open or less sheltered water is difficult and expensive, and the costs of dredging and breakwater costs increase rapidly with depth. These large costs of dredging involved, is probably the greatest constraint for the development of ports in the developing world. According to Bruun, site selection is mainly related to exposure by waves, currents and sediment transport. If possible, the port site should be placed in a sheltered natural area such as: behind an island or a shoal, in a deep natural bay or fjord on the coast, in a sheltered lagoon, tidal entrance or estuary. Besides these criteria, site selection is highly dependent upon environmental and physical parameters. These parameters are dealt with in PIANC's ICORELS in the ''Operational limit conditions'': astronomical tide, wind, changes of water level due to surges, waves (amplitude, period, direction), currents, visibility, ice.

A more recent port engineering book is ''Planning and Design of Ports and Marine Terminals'', written by Agerschou (2004). This book pays very little attention to the location of ports, and in some way emphasizes the need for awareness of the importance of site selection and a generic applicable framework. According to Agerschou, new ports and port extensions should be located where they will minimize the total sea and land transport costs to the economy of the country for the cargo in question, keeping in mind its different origins and destinations. The choice of a location is not only a matter of geography, but also of different construction costs for different sites. The author argues that in some cases, the optimum port location becomes a fairly simple, common-sense matter. However, it is far from simple as stated by Agerschou, as new port locations should be suitable for changing situations within timespans of maybe 100 years.

Another port planning book is written by Ligteringen & Velsink (2017). They elaborate on required information for fishery port development, however most of the information is common to all types of ports:

Table 3: Site selection information (Ligteringen & Velsink, 2017)

Sea	Port	Land
Tides: amplitude, type	Natural shelter	Access: road, rail
Winds: directions, durations, storms, directons	Vessels: type, size and number. Peak volumes, trend forecast	Settlement: size, fishermen, size, labour
Waves: types, height and periods, dominant directions	Distance to fishing grounds	Available services: water, electricity, fuel, workshops
Bathymetry	Nearness to commercial ports	Topography
Coastal conditions: littoral drift, siltation/erosion, dredging	Expansion possibility	Sub-soil profiles
Currents at different tide stages		Availability of materials: timber, gravel, rock, sand

In the below three tables, a first overview of possible site selection criteria is presented. These criteria come from site selection processes of Arcadis and from literature and desk study.

Table 4: General site selection criteria

Location	Hinterland	Utilities	Site state
Location of market	Inland water transport	Electricity state	Need for preparation
Nearby ports/plants	Railways	Telecommunication	Rock blasting/drilling
Safety distances	Airports	Water provision	River influences
Space for expansion	Road network		Site preparation cost
	Congestion degree		

Table 5: Social & environmental site selection criteria

Ecology	Climate	Labour/people	Land
Endangered species	Restriction by seasons	Availability of labour	Type of ownership
Protected areas	Cyclone prone area	Educational level	Land cost
Mangroves	Flood prone area	Resettlements	Land usage
Agriculture		Holy/sacred areas	Available land
Marine life		Corruption	Military restriction

Table 6: Constructional site selection criteria

Hydraulic	Bathymetry	Geology	Equipment
Waves/wind	Water depth	Morphology	Production on site
Tidal amplitude	Length of shelf	Dredging problems	Prefabricated
Currents	Coastal characteristics	Foundations	Trucks/barges/trains
Fog/mist/visibility	Sandbanks	Earthquakes	Temporary works
Tsunami's	Erosion/sedimentation		

2.2 Site selection in standards and guidelines

This section deals with three sources of site selection in standards and guidelines: PIANC, UNCTAD, and working practices from Arcadis. As mentioned earlier, a PIANC working group is developing PIANC report nr. 185 – Site Selection and Planning for New Ports and Marine Terminals on Greenfield Sites – Technical Guidelines. Although a draft version of the report will be ready end of 2018 at its earliest (section 5.3.2), the draft table of contents provides an indication of the site selection considerations, and shows that they are in agreement with the criteria mentioned above:

5. Identification and characterization of potential sites
5.1. Introduction
5.1.1. General background and motivation
5.1.2. Context within the screening process
5.2. First-level site characteristics
5.2.1. Context
5.2.2. Type of port location (baseline conditions and sheltering)
5.2.3. Access to deep water
5.2.4. Morphological aspects and need for breakwaters for coastal ports
5.2.5. Capital and maintenance dredging
5.2.6. Overall sensitivity to extreme conditions and events
5.2.7. Environmental value identification
5.3. Detailed site characteristics
5.3.1. Baseline physical conditions
5.3.2. Baseline environmental conditions and EIA
5.3.3. Baseline social conditions
5.3.4. Baseline land use designations and planning restrictions
5.3.5. Baseline land ownership
5.3.6. Baseline infrastructure
5.4. Data collection, inspection, investigation and survey
5.5. Site-specific stakeholder analysis

Site selection in PIANC 185 is defined as:

- The definition of the potential development area(s) to be considered
- The identification of one or more potential development sites
- The evaluation of suitability and potential of the sites identified
- The recommendation(s) for the preferred development site

Another well-known and extensive port planning handbook is developed by the United Nations Conference on Trade and Development (UNCTAD), published in 1984. Although this report is over 30 years old, the guidelines still remain valid and useful. UNCTAD has made consistent efforts to help developing countries in their task of extending and modernizing their seaports, and therefore can be of significant importance for this research on deep sea port developments in Myanmar. Many factors influence the location of the port, as stated by UNCTAD (1984), however four main criteria are most important for site selection: deep safe water at berthing points, sufficient land area, a labour force, good access to road, rail and waterway routes.

Besides the beforementioned references from literature, Arcadis has several guidelines and methods for site selection. The following process of site selection is provided by Arcadis, including two workshops:

Table 7: Process of site selection as provided by Arcadis

Step	Action	How
1	Prepare long list of sites	Desk study
2	Update and review long list of sites	Kick-off workshop
2	Identification of showstoppers	Kick-off workshop
2	Definition of parameters	Kick-off workshop
2	Understanding parameters content	Kick-off workshop
3	Site visits and data gathering	Data gathering
4	Parameter weighting	Stakeholder workshop
4	Site comparison	Stakeholder workshop
4	Ranking of sites	Stakeholder workshop
5	Sensitivity analysis	Report
5	Conclusions and actions	Report

2.3 Sustainable port development and site selection

Sustainable port development can be interpreted in many different ways, and every author has its own specific interpretation. 'Sustainability' itself is sometimes called an 'all-purpose word', indicating that the word has no clearly defined meaning and the user can give his or her own completion of the concept. Therefore it is very important to formulate an own interpretation of sustainability in port development for usage in this research, in order to frame the research and to provide the reader with a consistent definition. However there is one concept which is almost always mentioned in some way regarding sustainability: the Triple Bottom Line (TBL), first named by John Elkington (1997). TBL provides a framework for measuring success of organizations and developments using three lines: economic, social, and environmental. Elkington (1997) uses the terms profit, people, and the planet respectively. When aiming for sustainable development, some balance should be reached between the three lines because the balance provides a more robust template for long term development, in order to improve social and environmental conditions besides only the economic conditions.

This section elaborates on three different references with respect to sustainable (port) development, in order to extract suitable elements for the definition of sustainable port development in this research. The definition of sustainable port development is formulated in such a way that it is also applicable in the concept of 'sustainable site selection'.

2.3.1 PIANC 150: Sustainable ports

The purpose of the PIANC 150 report concerning sustainable ports is to create awareness about the advantages of implementing a green port philosophy and about what this philosophy means at present for ports and port authorities around the world and community support for port growth. The green port philosophy asks for a shift of thinking, in which a reactive 'ports *or* nature/environment' approach should change into a more proactive 'ports *and* nature/environment approach' (PIANC, 2014). This involves long-term thinking instead of short-term thinking: '*'if we don't know where we want to go, it makes very little difference that we make great progress.''*. The key elements in the green port philosophy as stated in PIANC 150 are:

- Long-term vision which strives towards an acceptable footprint on environment and nature
- Transparent stakeholder participation and stakeholder approved strategies to operate and grow
- Shift from sustainability as a legal obligation to sustainability as an economic driver
- Active sharing of knowledge with other ports and stakeholders
- Continuous striving towards innovation in process and technology

The Working Group itself prepared the following definition for a sustainable port: ''A sustainable port is one in which the port authority together with port users, proactively and responsibly develops and operates, based on an economic green growth strategy, on the working with nature philosophy and on stakeholder participation, starting from 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.

For several key issues like environmental quality (soil, water, air etc.), climate change & mitigation, habitat and integrity of ecosystems etc., PIANC 150 elaborates on challenges, issues and perspectives of the port authority. One of the most valuable aspects of this report are the subsequently given response options, which lists the available technologies and resources to cope with the challenges and issues. Some of the response options will be mentioned here, especially those which are easily applicable to Myanmar and related to:

Modalities & connectivity: develop dry ports or dedicated infrastructure, demanding modal splits in concession/lease contracts, promote water transport options for the links with the hinterland.

Air quality: Environmental Ship Index which awards clean and green ships with fee reduction.

Dredging impact: Prevent/reduce sedimentation and therefore dredging needs: design with hydraulic models minimizing inflow of sediments, use current deflector walls, develop beneficial re-use programs.

Energy and Climate Change mitigation: improve efficiency in logistic chain (less movements), use a Greenhouse Gas Toolbox which provides actions for ports to reduce emissions.

Habitat and species management health: eco-structures in new ports such as artificial reefs, water chambers within quay structures and reef blocks; ports may be used as hatchery as well.

2.3.2 UNEP MEA & UNEP EBM: Ecosystem Services

The Millennium Ecosystem Assessment (MEA) was carried out between 2001 and 2005 by the United Nations Environment Programme (UNEP) to assess the consequence of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being (Watson & Zakri, 2005). Since port developments have enormous impacts on both ecosystems and human well-being, maybe even the largest impacts of all types of industrial developments, the theoretical framework and results from the MEA can be of great importance for this research.

The assessment focuses on the linkages between ecosystems and human well-being as can be seen in Figure 6 and, in particular on ''ecosystem services''. Ecosystem services are the benefits people obtain from ecosystems, and was the subject of a workshop with stakeholders on port development in Myanmar, discussed further on in this report.

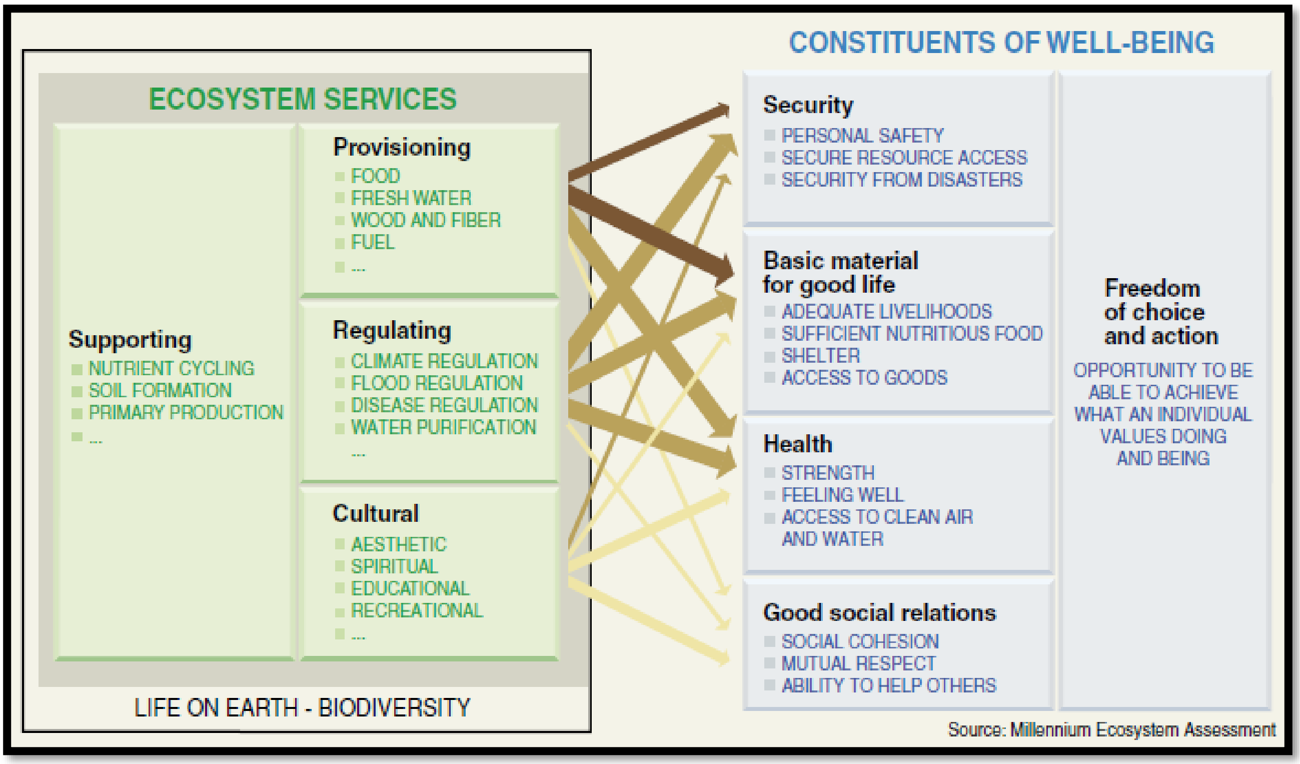


Figure 6: Ecosystem services and human well-being according to Watson & Zakri (2005)

These ecosystem services can be categorized in four groups: provisioning services, regulating services, cultural services, supporting services. The MEA examines how changes in ecosystems and therefore in ecosystem services, influences human well-being. Human well-being is assumed to have multiple constituents: basic material for a good life, health, good social relation, security, and freedom of choice and action. It is necessary to describe three of these constituents a bit more detailed, because port developments have large influence on these three:

- Basic material for a good life: secure and adequate livelihoods, enough food, shelter, access to goods
- Health: having a healthy physical environment, such as clean air and access to clean water
- Security: secure access to natural and other resources, security from natural and human-made disasters

Approximately 60% of the ecosystem services evaluated in the assessment are being degraded or used unsustainably, as concluded in the MEA. The situation of the ecosystem services in a certain area can be of great use as measure for sustainability within that area. Ecosystem services can be directly linked to the earlier mentioned Triple Bottom Line. The 'people-line' is directly related to the human well-being, arising from the ecosystem services. The 'planet-line' is related with almost every ecosystem service, as most services e.g. food, fresh water, flood regulation, wildlife habitats etc. are directly provided by the planet. Finally, the 'profit-line' (nowadays also named prosperity) is related with the economic costs associated with damage to the ecosystem services. Because of this relation of TBL and Ecosystem Services, it can be stated that degradation of Ecosystem Services (decrease of well-being, decrease of the ecosystem, and high economic costs) in a specific area cause a degradation of the sustainability (decrease of the people, planet, profit conditions).

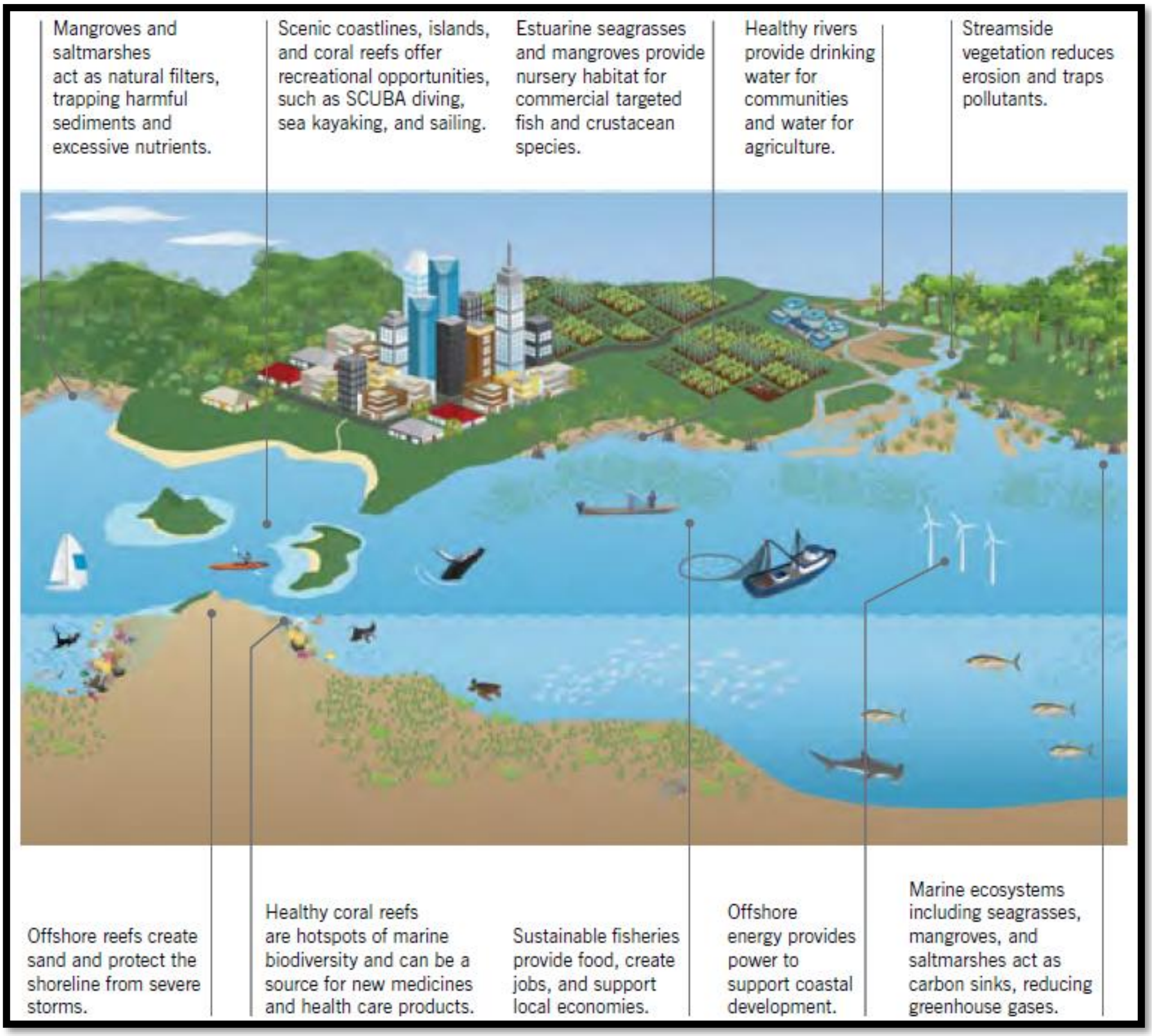


Figure 7: Ecosystem services (UNEP, 2011)

Using these ecosystem services in management of coastal ecosystems, is often called ecosystem-based management (EBM). EBM is aimed at conserving and sustaining ecosystem services to benefit current and future human generations. Similar to Watson & Zakri (2005), UNEP (2011) states that healthy marine and coastal ecosystems provide many valuable services. Among the most productive ecosystems on the planet, oceans and coasts ensure the well-being for a growing global population. Port developments greatly affect these productive ecosystems, and the future role of these ecosystems for human well-being depends increasingly on the capacity of countries to manage human uses and impacts of (port) developments. As UNEP (2011) puts it: ''Central to a transformational response to decades of overfishing, pollution and unplanned urban development will be moving from sectoral marine and coastal management, to a joined approach that marries the seemingly competing interests for ocean and coastal resources and space, such as environment, tourism, fisheries and energy generation, within a robust framework and a spatial planning perspective. This is central to ensuring equitable access among diverse interests and users.'' The ecosystem services as defined by UNEP. (2011) can be found in Figure 7. It is a perfect example to describe the influence of port developments on the ecosystem and ecosystem services, because it is possible to imagine a port in this figure and its corresponding impact.

The Ecosystem Approach defines a series of principles to guide management towards long-term sustainability of marine and coastal ecosystems. With this Marine and Coastal Ecosystem-Based Management (EBM) Guide, UNEP tries to assist countries and communities to take steps towards making EBM operational by providing operational considerations based on practical experience in an accessible language. In this research on site selection, not all ecosystem services will be included because port development affects one ecosystem service more than other ecosystem services. Therefore a prioritization will be made based on experiences from the case-study, and insights from local stakeholders. This will be discussed in more detail in sections 5.4.4 and 6.3.1.

Research is going on with respect to valuation of Ecosystem Services. The Economics of Ecoystems and Biodiversity (TEEB) is a global initiative focused on ''making nature's values visible''. Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, capture those values in decision-making.

For this research, valuation of ecosystem services can be of vital importance in order to rank and quantify proposed port sites based on an increase or decrease of the value of the specific ecosystem service. TEEB provides many different valuation techniques, of which some will be described in this section. In their report ''TEEB Ecological and Economic Foundations'' a conceptual foundation to link economics and ecology is provided, to highlight the relationship between biodiversity and ecosystem services and to show their importance for human well-being. TEEB define ecosystem services as ''the direct and indirect contributions of ecosystems to human well-being''. In this research on site selection, these valuation techniques are not applied, however they are mentioned in this section for additional information. Actual measurements of ecosystem services should be split into a.) the capacity of an ecosystem to provide a service (e.g. how much fish can a lake provide on a sustainable basis), and b.) the actual use of that service (e.g. fish harvesting for food or for use in industrial processing). Measurement of the importance (value) of that fish in terms of nutrition value, a source of income and/or a way of life is then part of ''human value domain'' (de Groot, Fisher, & Christie, 2010). They elaborate upon the following valuation methods:

Direct market valuations

- *Market price-based approaches* are most often used to obtain the value of provisioning services, since the commodities produced by provisioning services are often sold on e.g. agricultural markets. The price of a commodity times the marginal product of the ecosystem service is an indicator of the value of the service.
- *Cost-based approaches* are based on estimations of the costs that would be incurred if ecosystem service benefits needed to be recreated through artificial means: the avoided cost method, the replacement cost method, and the mitigation cost method.
- *Production function-based approaches* estimate how much a give ecosystem service contributes to the delivery of another service or commodity which is traded on an existing market. In other words, the PF approach is based on the contribution of ecosystem services to the enhancement of income or productivity.

Revealed preference approaches

- *The travel cost method* which is mostly relevant for determining recreational values related to biodiversity and ecosystem services. It is based on the rationale that recreational experiences are associated with a cost (direct expenses and opportunity costs of time). The value of a change in the quality or quantity of a recreational site can be inferred from estimating the demand function for visiting that site.
- *The hedonic pricing method* uses information about the implicit demand for an environmental attribute of marketed commodities. E.g. houses or property in general consist of several attributes, such as the proximity of a house to a forest or whether it has a view on a nice landscape. The value of a change in biodiversity or ecosystem services will be reflected in the change in the value of property.

Stated preference approach

- *Contingent valuation method* uses questionnaires to ask people how much they would be willing to pay to increase or enhance the provision of an ecosystem service, or alternatively, how much they would be willing to accept for its loss or degradation.
- *Choice modelling* attempts to model the decision process of an individual in a given context. Individuals are faced with two or more alternatives with shared attributes of the services to be values, but with different levels of attribute.

2.3.3 *Port of the future*

Another concept of sustainable port development is the 'no-impact' port development concept. In 'Port of the Future' from Deltares (2015), it is stated that the growing number of port development project causes recognition of the need to shift economies and social structures towards more sustainable models. There is a need for innovative solutions for port development which are in harmony with the ecosystem and which are adaptable in periods of uncertainty. The main motivation for the report 'Port of the Future' is to find opportunities to facilitate co-creation in sustainable or green port development and implementation of these green ports in order to turn traditional port development into green initiatives.

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

Deltares (2015) makes use of the earlier mentioned EBM from Agardy et al. (2011), by aiming for ecosystem-based port development resulting in a no-impact port. The sustainable or green port development consists of optimizing the economic, environmental and social benefits (the triple bottom line concept) of ports. Awareness for sustainability in combination with green growth is rising, but port investments are increasingly financed by private parties and most countries rush to expand, upgrade or develop their ports to receive mega vessels. In Port of the Future, the approach of EBM is used which aims to restore and protect the health, function and resilience of entire ecosystems for the benefit of all organisms. Aim is to realize a 'no-impact' port development: a port that has no negative impact on the ecosystem, which recognizes that the port, sustainable port operation, the associated human population and economic/social systems are seen as integral parts of the ecosystem.

Summarized by Deltares (2015): 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.

The definition of a green or sustainable port, as given by Deltares, is as follows: 'A sustainable port is a port which has achieved and is maintaining a balance in economic, environmental and social extent for the surrounding local region, and aims to create a high economic efficiency in the port, good ecological environment and social considerations.'

The report 'Port of the Future' is followed up by Schipper et al. (2017) in their report 'A sustainability assessment of ports and port-city plans: Comparing ambitions with achievements'. In this report, port masterplans are evaluated based on nine key performance indicators (KPI) for measuring sustainability, in the TBL division. The following sustainability pillars or KPI's, are used:

Social	Environment	Economic
Employment	Water quality	Cargo growth
Well-being	Eutrophication	Cruise tourism
Water purification	Air quality	Investment

The method of evaluating port masterplans based on these nine KPI's, can also be used to rank port locations before anything is developed, and has therefore potential to carry out in this research. However, port masterplans are not yet common in Myanmar and often do not exist, which will be discussed further on in this research. Nevertheless, this research can be of great significance because the nine KPI's are selected from a longer list of KPI's, and can be used as criteria for sustainable site selection. Figure 8 describes the method from Schipper et al. (2017).

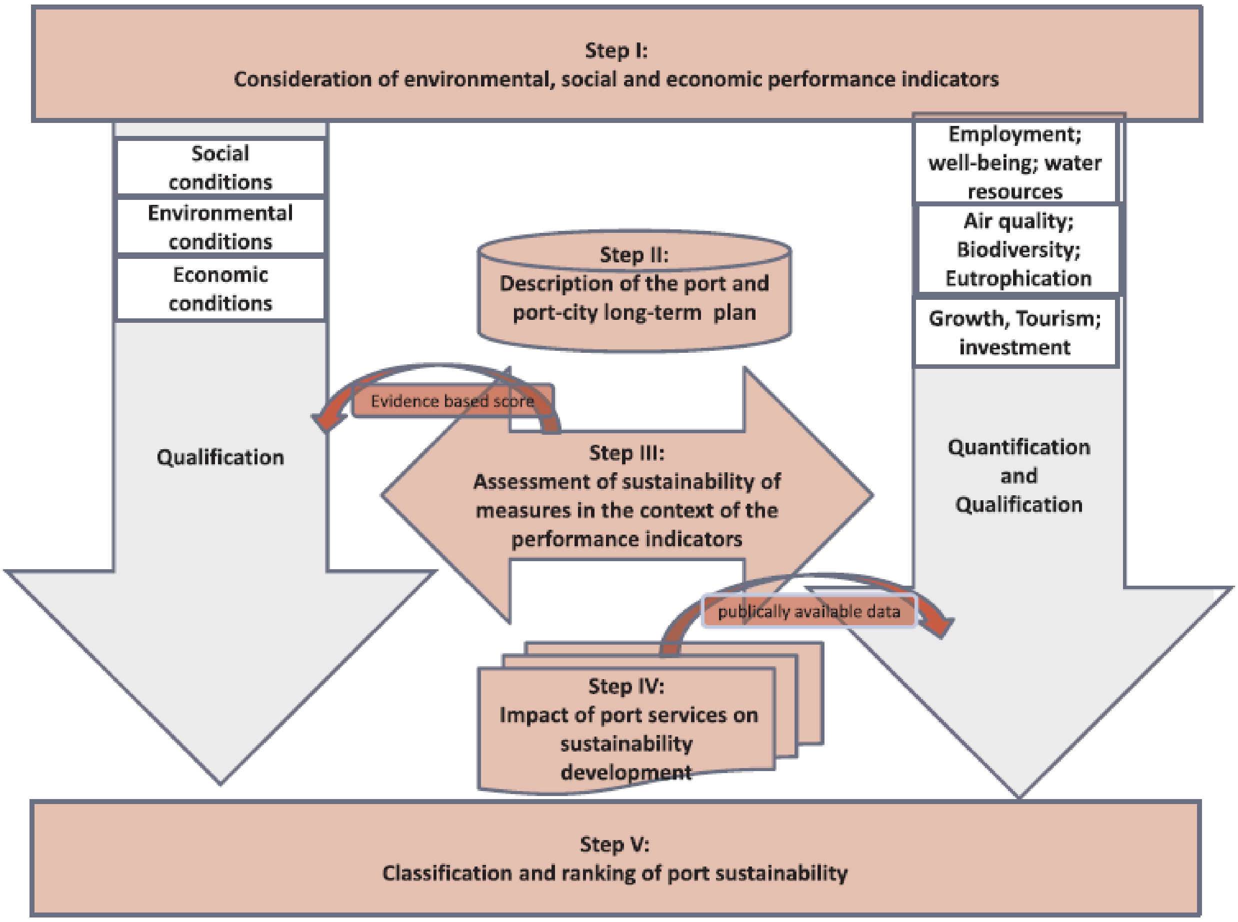


Figure 8: Port assessment method (Schipper et al. 2017)

The port assessment method has been developed for considering sustainability KPI's in port plans and masterplans (step I and II), by comparing the qualitative description of the sustainability in port and port-city long-term plans (step III), with the sustainability assessment of publicly available data from comprehensive studies in the port-city integration (step IV). The impact of port services on sustainability development expresses the sustainability conditions in classes in order to form synergies with the overall objectives of sustainable port development (step V).

2.3.4 Stakeholder-inclusive approach

Another method which can help in achieving sustainable port development, is the stakeholder-inclusive approach. Including stakeholders comprises more than just providing information to stakeholders. Different participatory processes such as co-learning, co-creation and co-operation are needed which help in achieving a more sustainable port design. To integrate engineering, ecology, economy and governance as mentioned before, early and transparent stakeholder engagement is needed in order to strive for an open dialogue, accountability and collaboration (Vellinga et al. 2017) Two specific examples of stakeholder engagement mentioned in their research are:

1. Identifying different stakeholders: researchers, public sector, private sector, users
2. Organizing workshops with stakeholders of different levels to understand the local situation and drivers of port development

Application of the stakeholder-inclusive approach method in sustainable port development is discussed by Slinger et al. (2017). In their research, it is emphasized that because of the world changing around us, traditional problem solving approaches which rely on knowledge and skills from individual disciplines are incapable of addressing multi-faceted problems and difficulties. Therefore a more holistic, pluralistic and participatory approach is needed which is able to survive in a highly interconnected, complex and turbulent environment. As stated by Taneja (2013), more than ever large infrastructure projects denote thinking in terms of uncertainty, flexibility and adaptability.

In their literature study, five sustainability guiding principles for an alternative approach to sustainable port development are derived of which four are relevant and useful for this research on sustainable site selection:

1. A more sustainable port can be realized by embracing the four perspectives of engineering, economy, ecosystem services and governance in an integrated approach to port development
2. Intrinsic to this approach is working with nature with a focus on achieving project objectives in an ecosystem context that not only minimize the potential long-term negative impacts of port development, but seek win-win cost-effective design solutions
3. Early and transparent engagement of a broad range of stakeholders is required from the start to give meaning to the term 'sustainable port' in their specific context, to identify opportunities for added value and to facilitate implementation. (Traditional port development in contrast, is associated with long lead times due to conflicting interests and lack of mutual understanding of involved stakeholders)
4. Co-creation with stakeholders to identify their values, seeking opportunities to create or enhance biodiversity, and encouraging open dialogue, collaboration, and commitment of the stakeholders throughout the project, highlight the approach

According to de Vriend & van Koningsveld (2012), stakeholder involvement is important for two reasons. First because traditional infrastructure projects often encounter growing resistance from people who will be affected, because of lack of support. This resistance is often dismissed as the ''not in my backyard'' syndrome, however project developers have to realize they are interfering with these people's social habitats. Secondly, local stakeholders know very much about the area they live, and that knowledge can be very useful for understanding natural systems and processes, and how they will interact with manmade structures. In this way, stakeholder involvement can inspire to come up with new solutions. So involving the public provides insights into local systems and natural processes, and is likely to lead to better solutions that stakeholders are more likely to accept.

2.3.5 Adaptive port planning

The third approach encompasses planning of ports under uncertainty. Planning under uncertainty is becoming more popular and one of the drivers for sustainable port development. Already in 1989, Per Bruun mentions the importance of port planning considering future developments, in particular the general increase in ship sizes, because of the huge capital investments involved in port structures (Bruun, 1989). Nowadays, not only the predictable aspects such as the increase of ship sizes should be accounted for, also unpredictable effects such as change in transport models or manufacturing methods.

Taneja (2013) presented a framework known as Adaptive Port Planning (APP), which deals with planning under uncertainty. Adaptive Port Planning, compared to traditional port planning, incorporates uncertainty and flexibility into all stages of port planning. APP aims at developing alternatives which are able to change, learn and adapt over time. Implementation of APP in a site selection framework should be investigated, because including measures to deal with uncertainty is more convenient in an early stage of port development than at the end of port development. Besides, APP can help reaching sustainability goals in port development. From the past it can be seen that adaptability is important. This research will not focus on APP in detail, however strong consensus is present, also at Arcadis, about the need for adaptive port designs. APP in this research means that the masterplan and the proposed site should be adaptive and there should be possibilities for future expansion.

2.3.6 World Bank definition and sustainability requirements

For developing countries, satisfying the requirements set by development banks is very important because these countries rely on loans and investments from these development banks. The World Bank is the largest and most important development bank, and in their report 'The World Bank Environmental and Social Framework' (ESF), the World Bank sets out the World Bank's commitment to sustainable development through a bank policy and a set of environmental and social standards (ESS) that are designed to support Borrowers' projects. The ESF sets out ten mandatory environmental and social standards of the World bank in relation to the projects it supports through investment project financing (World Bank, 2017):

1. Assessment and management of environmental and social risks and impacts
2. Labor and working conditions
3. Resource efficiency and pollution prevention management
4. Community health and safety
5. Land acquisition, restrictions on land use and involuntary resettlements
6. Biodiversity conservation and sustainable management of living natural resources
7. Indigenous peoples/sub-Saharan African historically underserved traditional local communities
8. Cultural heritage
9. Financial intermediaries
10. Stakeholder engagement and information disclosure

These standards are designed to help borrowers to manage the risks and impacts of a project and improve their environmental and social performance. The Bank will only support projects consistent with these ESS's. The World Bank Group Strategy sets out the corporate goals of ending extreme poverty and promoting shared prosperity in all its partner countries. Securing the long-term future of the planet, its people and its resources, ensuring social inclusion, and limiting the economic burdens on future generations will underpin these efforts. The two goals emphasize the importance of economic growth, inclusion and sustainability – including strong concerns for equity.

2.3.7 Definition of sustainable port development

Based on the previous references on sustainable (port) development, a new definition of sustainable port development will be formulated which serves as the basis of this research. This definition is formulated such that it can also be related to site selection, which is the main subject of this research. From section 2.3.1 and 2.3.3, and the mentioned methods ecosystem-based management in section 2.3.2 and the stakeholder-inclusive approach in section 2.3.4, three frequently used aspects are chosen for the definition which will be the core of this research:

- The Triple Bottom Line division in people, planet and prosperity (or social, environmental, economic)
- Early and transparent stakeholder participation: a stakeholder inclusive and co-creative approach
- Ecosystem services, being the core of ecosystem-based management

The definition of sustainable port development will provide a scope and guidance during this research:

''Sustainable port development anticipates the needs of future generations, while assuring a balance in social, environmental and economic extent for the port's benefit and the surrounding local region. This balance can be achieved and maintained during deep sea port site selection by conserving or improving relevant ecosystem services, which represent the social, environmental and economic conditions in the surrounding region. Starting point of this sustainable development is a long-term vision in which early and transparent stakeholder participation from both public and private parties is encouraged, in order to facilitate co-creation by identifying values and opportunities to enhance ecosystem services. An end point is not defined, as sustainable development is an ongoing process.''

2.4 Initial site selection framework

As stated in the research objectives in section 1.3, a research objective of this research is the development of a framework for sustainable site selection in developing countries. For the development, use will be made of a comprehensive case study containing fieldwork in Myanmar and data and insights from the case study will be used for development of the framework. However, before moving into the fieldwork, an initial framework should be present for having basic understanding of a possible site selection process. This initial framework will be further developed and enhanced in section 5 based on findings from the case study.

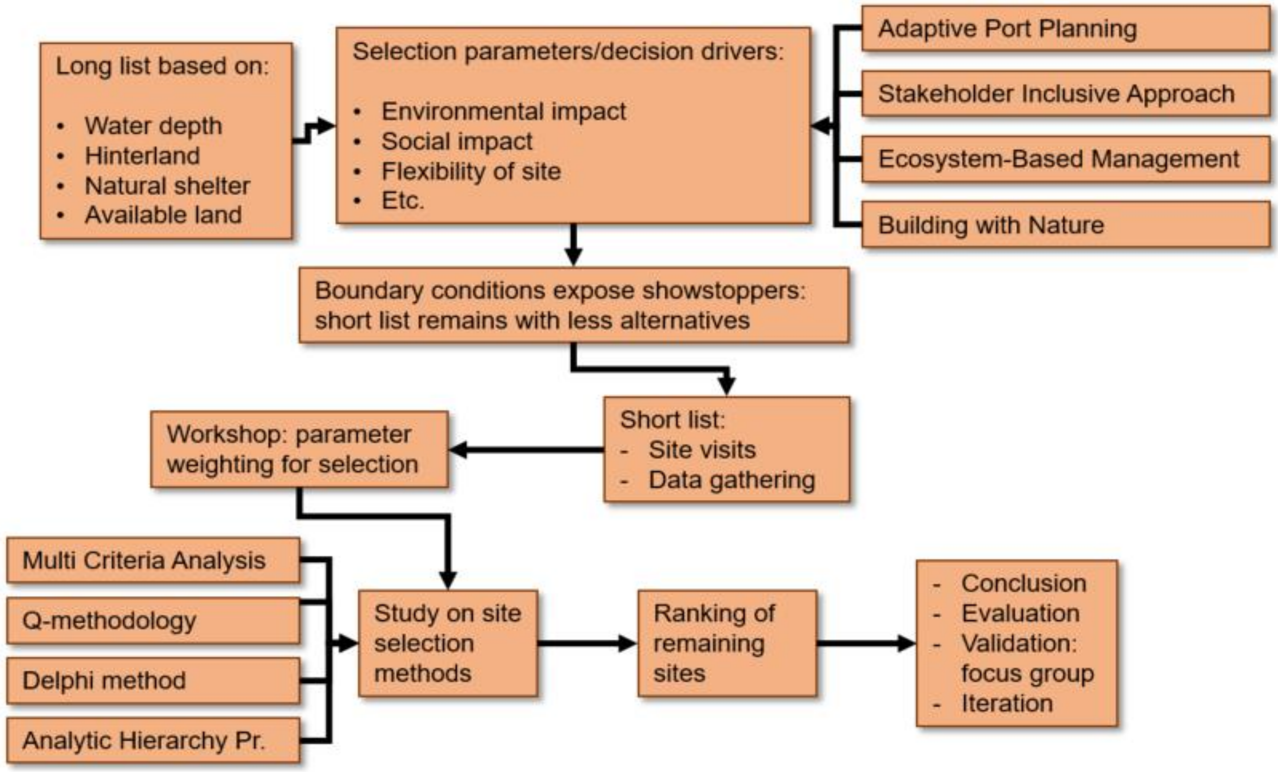


Figure 9: Initial sustainable site selection framework (see section 5.6 for improved final framework)

An important aspect of this research is to investigate whether it is possible to implement sustainability measures like APP, SIA, EBM and BWN at the beginning of the port planning process, during the site selection phase. Early acknowledgement of the need and embedment of sustainable measures avoids situations in which sustainability is only considered during the preliminary or final design phase. In these phases, sustainability can only be achieved on minor scales, while selecting a port site can have major influences on sustainability of the port under consideration. It is important to mention that the framework above is adapted and enhanced, and that the initial framework will not be used for the final site selection process. For example, the BWN philosophy and the APP framework are not included in this literature review and in the final framework in section 5.6, due to time considerations. Besides, the MCA evaluation method and the pairwise comparison method from the AHP is used (section 5.3).

2.4.1 Framework EBM-approach marina development

For development of the site selection framework in this research, use will be made of the framework for an ecosystem-based approach to sustainable marina development, developed by De Boer (2016). This framework is developed for the initial stages of marina development, and aims at filling an observed gap in practical guidance. The framework takes an ecosystem-based management approach to development, and the ecosystem is considered to be at the basis of sustainable development.

An interesting aspect of this framework is the ecosystem assessment, aimed at assessing the interaction between the marina and its natural environment. A ''marina-ecosystem interrelations tool'' has been developed, to provide insights on the interactions between a marina and its natural environment. Aspects of the framework, especially regarding the ecosystem-based management approach, will be used to set up the framework for this research on site selection. The framework of de Boer can be found in Appendix A.

3 DEEP SEA PORT DEVELOPMENT REQUIREMENTS

Planning future port developments and site selection asks for thorough understanding of the port system and the wishes and requirements for the port under consideration. To organize data and information gathering for the site selection process in this research, use is made of the basic planning procedure according to Thoresen (2014) for port development. One should always remember that ports often define their own needs. Some ports are predominantly container ports, others are bulk ports or multi-purpose ports. Depending on the character of existing traffic and expectations about future potential, the port's need and future capacities will vary. This chapter deals with the elaboration of user's needs and values of a deep sea port.

3.1 Motivation for deep sea port development

Every news article, stakeholder or report agrees: Myanmar needs an own deep sea port, apart from the ports developed to serve India, China and Thailand. There are several reasons for deep sea port development, which are presented in the below ranking, based on Myanmar's priorities:

1. To cater for a growing economy:

The population of Myanmar amounted 60 million in 2011. JICA (2014) uses a 'container producing factor' to provide a rough estimate of the nationwide container throughput in Myanmar, in order to emphasize the necessity of a deep sea port in Myanmar. With a container producing factor of 0.025 (container use per inhabitant), the nationwide container throughput of Myanmar could rise towards 150 million TEU's. The GDP of these 60 million inhabitants is increasing rapidly, which is likely to result in a fast growing transport demand.

2. To cater for larger vessels:

According to a major shipping line serving Myanmar to and from Singapore, the largest inter-connecting port in the region, the current maximum size of feeder ships is 1000 TEU, which is a bottleneck of the Singapore/Myanmar service route. 16 feeder service vessels are currently deployed between Singapore, Port Klang and Yangon of which the largest has a maximum capacity of 1.118 TEU (JICA, 2014). The export and especially import cargo, is heavily stagnated at Singapore and other feeder-connecting ports resulting in a slow economic development of shipping.

3. To boost the economy:

In Myanmar, boosting the economy is important after years of low economic development, however this is not a main motivation for a new deep sea port because the lifting of economic sanctions and the new democratic regime already account for a large boost of the economy. Developments can already hardly keep up with this economy boost, so another boost by port development is not needed.

4. To lower logistics costs:

Catering for larger vessels is needed because of stagnation at the most important transshipment hubs, but also to lower logistics costs. Economies of scale cause larger vessels to be cheaper than smaller ones. According to the shipping lines serving Yangon Port, assuming a maintained maximum draught of 9 m, the maximum size of the deployed ship will be 2.000 TEU. Demand forecasts expect at least 10% cargo growth every year for the coming 10 years, which causes all 2.000 TEU ships to be fully loaded (JICA, 2014). Logistics costs can be lowered by deploying larger ships, which is only possible with larger draughts.

5. To compete as a transshipment hub:

On the short term, Myanmar should focus on import and export instead of transshipment. The country has got a large economy with fast growing containerized trade. After establishment of one or more gateway seaports, competing as a transshipment hub can be feasible because of Myanmar's strategic location. At this moment, Myanmar is not capable of competing as a transshipment hub with the two largest hubs in the region: Port of Singapore and Port Klang in Malaysia. This is mainly caused by economies of scale and shipping lines which have their fixed transshipment hub in the region (Jonathan Beard, interview, 17-11-2017).

The main motivation or objective for new deep sea port development in this research is to cater for the growing economy of Myanmar itself, which means serving the hinterland of Myanmar itself, in this case mainly Yangon and Mandalay as largest and most densely populated areas. This hinterland directly determines the most important distance to the markets at Yangon and Mandalay, which should be minimized.

3.2 Planning process

The list presented below served as a guideline for data gathering and as mentioned, is based on the port planning procedure from Thoresen (2014). Normally, most parts of the planning process as presented below are already carried out when site selection takes place. In this research, because of the vaguely defined project information, first some port planning (cargo, commodities, ships etc.) is necessary before proceeding towards the site selection phase. Therefore this list provides a practical guideline for data gathering and port planning before selecting the optimum site. Some aspects from this planning procedure are not relevant for site selection and will be neglected. On the other hand some aspects are added based on judgement of the researcher and on site selection criteria from Arcadis. The original checklist can be found in Appendix B.

a. Scope of work

- **Introduction**: client, type of project, geographical location
- **Background**: existing ports/infrastructure/traffic/Special Economic Zones (SEZ)
- **Scope of project**: project boundaries
- **Basic data**: relevant documents and data

b. Catalogue of key users and stakeholders

- A comprehensive list of stakeholders can be found in Appendix D.

c. Recording of stakeholders' and user's needs

- **Type of port**: tool port/service port/landlord port, gateway vs. transshipment
- **Future commodities and cargo**: type of cargo, present and future cargo tonnage, volume and origin
- **Future traffic:** forecast of seaborne and overland transport in the area, future import/export cargo
- **Types and specification of ships**: ship types, ship sizes, ship origin and destinations
- **Coastal areas and maritime conditions**: approach channel, sailing restrictions, need for shelter
- **Land area requirements**: present and future needs for land areas, access roads, utilities
- **Adaptive Port Planning**: population increase, economic/traffic growth, industrial developments

d. Site selection

- **Potential areas**: locations from long list and subsequently short list
- **Hinterland connections**: existing and planned infrastructure: inland water transport, road, rail, pipes
- **Topographical**: description of land area, climatologic conditions
- **Geographical**: identification of soil, OPEX/CAPEX dredging, stability of coastline (erosion/accretion)
- **Oceanographic/hydrographical**: wave/wind climate, tidal variations, water depth, currents, cyclones
- **Environmental**: coastal/marine habitats, protected habitats/areas, mangroves, noise/air pollution
- **Social**: cities nearby, availability of labor, military restrictions, social issues
- **River aspects**: river discharge (water and sediment), flow velocities

e. Development of framework (from stakeholder consultation)

- Criteria/considerations for current and past site selection and port developments in Myanmar
- Views from stakeholders on the needs for deep sea ports in Myanmar
- Individual needs for port development and site selection of the stakeholders
- Importance of economic, environmental and social values for port development in Myanmar
- Views from stakeholders on their interpretation of sustainability in port development and site selection
- Overview of port development and site selection policy in Myanmar
- Selection parameters and their importance for selection deep sea port sites
- Differences and similarities between Myanmar site selection and international site selection

In the upcoming section, part c. 'Recording of user's needs' will be discussed. Most user's needs are not location-specific, and can therefore be presented upfront of the site selection. E.g. if a user needs to import to a location, that is a location-specific need. Part d. 'Site evaluation' is location-specific and will be elaborated upon during the site selection phase of this research in chapter 6.3.

3.2.1 Port model

Regarding the required and preferred type of port, three common port models are distinguished (Deltares, 2015). The port model should be known when considering the financial viability of basic infrastructure in a port by distinguishing the several stakeholders within a port and their objectives.

- **Tool port**: in this port model, the Port Authority (Myanmar Port Authority in this research) owns the land, the fixed and mobile assets, and performs regulatory and port functions. The port is controlled by a governmental body, and the same organization has the responsibility for developing the basic infrastructure, superstructure (terminals) and equipment as well as executing operational activities. These models rely heavily on government funding.
- **Landlord port**: in this model, the public Port Authority owns and maintains the port's basic infrastructure (breakwaters, quays, basins, connecting infrastructure), and is responsible for the economic management of the port and the maintenance of basic port infrastructure (wharves, berths). The quay areas are leased out to private companies which provide and maintain their own superstructures (terminal equipment). The private terminal operators must rely on a viable business case.
- **Private service port**: in this model, the public Port Authority has no longer a role or interest in port activities. Port land is owned by the private sector and all operational activities are performed by the private sector. This model is often applied in two cases: in port which supports the core activities of a company (oil, mining), or in ports which are purely developed as commercial enterprise.

The World Bank distinguishes between four different port models, as presented in Figure 10.

Basic Port Management Models

Type	Infrastructure	Superstructure	Port Labor	Other Functions
Public Service Port	Public	Public	Public	Majority Public
Tool Port	Public	Public	Private	Public/Private
Landlord Port	Public	Private	Private	Public/Private
Private Service Port	Private	Private	Private	Majority Private

Figure 10: Port management models as defined by the World Bank (2007)

The most promising port model for Myanmar is the landlord port. A tool port cannot sustain, because of a lack of funding possibilities from the government. The port authority depends completely on the budget division by the national government, and MPA is not receiving the highest priority. Besides, current equipment is heavily outdated which asks for quick investments. Lastly, private sector influence increases port development knowledge within MPA, which can act as capacity building. Therefore, influence from the private sector is indispensable. In this research, a division considering three port models is sufficient to capture all models. A public service port can hardly be viable in Myanmar, because budgets are very low and private investments are required.

3.2.2 (Future) commodities

Going forward with western sanctions easing the country's economy opening up, Myanmar is likely to increase its exports in natural resources, farm products, marine products, and textiles. In return, it would be importing consumer durable items, electronic products, and capital goods. This kind of trade pattern would generate export requirements in general cargo, (dry) bulk and containerized cargo. On the other hand, import would mostly be carried out in general cargo and containerized cargo (Arcadis, 2013). Import cargo has a more variable distribution of cargo flow than the export cargo flow.

According to JICA (2014), the main import commodities in Yangon port are containerized cargo, liquid fuel (gasoline, diesel and jet fuel), cement, cooking oil, iron material (billet), steel products, cars, and general cargo. Main export commodities are containerized cargo, timber, and rice.

Over the last decade, Myanmar has recorded rapid economic reforms and a strong export growth. Myanmar has undergone market-oriented economic reforms and is becoming an important trade and investment destination in ASEAN. Therefore, a National Export Strategy (NES) is drafted in 2016, to guide Myanmar's exports, increase competitiveness of companies, improve business environment for development, and expand the country's trade (JICA, 2017). A seven priority sector is set up by the NES based on the vision *''Sustainable export-led growth and prosperity for emerging Myanmar''.* These seven priorities are current important commodities, and will be given high priority in the future.

Rice

- Myanmar was once one of the top exporters of rice in the world. Now it accounts for only 1.8% of the national exports in 2011.
- The underexploited sector has a high potential for socio-economic impact, food security and significant growth potential.

Beans, pulses and oilseeds

- Myanmar is one of the largest cultivators of beans, pulses and oilseeds in the world
- Beans and pulses accounted for 9.6% of Myanmar's total exports in 2012.

Fisheries

- Myanmar has abundant inland water resources, and substantial fisheries in major rivers and coastal areas.
- Like rice, fisheries have large potential to contribute to food, employment and economic development.

Textiles and garments

- Textiles and garment production function as the main manufacturing industry.
- The industry emerged in 1990 and was ranked as the largest export item in 2000. Due to international sanctions, the industry declined. Due to lifting of sanctions, potential of the industry can be unlocked.

Forestry product

- Myanmar has got 100 wood-based industries, which account for 1.0% of the GDP.
- Myanmar is the world's leading exporting country of tropical hardwood log.
- This sector has got enormous potential, however Myanmar's forestry products in the international market do not comply with the international standards and certification requirements

Rubber

- Myanmar is only ranked 13th in the world rubber market ranking. However, the sector can have large socio-economic impacts and become a driver of employment and revenues.

Tourism

- Myanmar offers large amounts of forest reserves, beaches and UNESCO World Heritage sites which present a huge potential for tourism. Potential of this sector is still underexploited.
- A tourism masterplan has been launched in 2013 to increase competitiveness and conserve areas.

3.2.3 *Cargo demand forecast*

Cargo forecasts are indispensable for planning ports and determining land requirements. Several methods for cargo forecasts exist, mostly based on economic and demographic indicators. This section will elaborate on three methods as used by Arcadis, of which the results will be discussed and averaged to strive for a reliable forecast:

1. Top-down forecast method using GDP growth
2. Top-down forecast method using country comparison
3. Bottom-up forecast method using extrapolation of key commodities

Top-down method using GDP growth

Forecasting literature comprises of trend extrapolation techniques and the use of causal relations, and indicates that causal relations are more suitable for long term estimates than trend extrapolation. The relation between economic activity (measured in GDP) and freight transport (measured in tonnes, tonne kilometres or TEU) is often recognized. According to the research of van Dorsser, Wolters & van Wee (2012), a relation between GDP and port throughput is likely to hold because port throughput is a function of import and export of goods, which are in their turn both a function of GDP. The GDP itself should also be forecasted, in order to obtain cargo forecasts. Jansen (2014) recommends using the GDP forecast of IMF (International Monetary Fund) for GDP growth, based on neo-classical theory which states that economic growth is a product of labour force growth, capital accumulation and technological progress. The IMF forecast is only presented for 4 years ahead, so extrapolation is necessary. Besides GDP forecasts from IMF, GDP data from the Asian Development Bank and World Bank will be used. Table 8 shows that both GDP growths of the past are almost similar.

Table 8: GDP growths per year by the IMF and ADB

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
IMF	7.3%	8.4%	8%	7%	6.1%	7.2%	7.6%	7.5%	7.5%	7.5%
ADB	7.3%	8.4%	8%	7%	5.9%	7.7%	8.0%			

In 2014, three possible Growth scenarios were determined by the Asian Development Bank, as presented in Table 9. Myanmar's growth is uncertain and will depend on the speed of technical progress, changes in country-specific structural conditions, and on the implementation of economic reforms and policies. By focusing on key sectors such as agriculture, energy and mining, infrastructure, manufacturing, telecommunications, and tourism, GDP growths of 8% each year can be realized (Asian Development Bank, 2014).

Table 9: Growth Scenarios for Myanmar by the Asian Development Bank (2014)

Growth scenario	GDP per capita (2030)	GDP changes from 2010 level
Low growth (5% - 6%)	2.051 – 2.479	More than 2 times
Medium growth (7% - 8%)	2.992 – 3.603	More than 4 times
High growth (9% - 10%)	4.333 – 5.201	Almost 6 times

Contrary to these large GDP growths, the World Bank reported a small economic slowdown in 2016: ''Growth has moderated from 8% in 2014 – 2015 to 7.3% in 2015 – 2016, and is projected to slow further to 6.5% in 2016 – 2017. Consumption demand has decelerated due to high inflation, which in addition to ongoing structural constraints, exchange rate volatility and a perceived lack of clarity in economic policies, has dampened new investment flows.'' The World Bank expects GDP growths of 7.1% in the period between 2017 and 2020 (World Bank, 2016). It can be concluded that most sources of GDP projections agree on a growth in the order of 7-8% per year. Important to mention is the target of Myanmar's President H.E. U Thein Sein for annual GDP growth rate at 7.7% for the current five-year development plan (JICA, 2017).

Myanmar Industrial Port (MIP) forecast

MIP (private port operator) forecasts container cargo growth based on two times the GDP growth. This factor of two is a transport multiplier indicating the relationship between cargo growth and GDP growth. Container transport grows two times faster than GDP in this case. Eventually, the multiplier has to move towards one because port throughput in relation to GDP growth cannot grow in an infinite way (Jansen, 2014).

At this moment (2017), Myanmar handles 1 million TEU/year. MIP assumes a GDP growth of approximately 7% each year, and therefore a container growth of 14% - 15% each year. This projection will probably hold for a few years, however is not realistic for determining the long term container forecast. From 1 million TEU in 2017 towards 3 million TEU within 10 years is therefore realistic (Chief Financial Officer MIP, interview, 31-10-2017):

Table 10: Container forecast by MIP for whole Myanmar (in TEU/year)

2017	2020	2023	2026	2030
1.000.000	1.520.000	2.313.000	3.518.000	6.153.000

Arcadis forecast

Arcadis used GDP data between 2002 and 2011. During these years GDP growth rates were extremely high, sometimes in the order of 50%. On the other hand, container growth rates were relatively low because of the closed market situation of Myanmar. This combination is not representable anymore for the situation after 2011 and therefore the results from Arcadis are not considered reliable. For completeness, the container forecasts are given below, for an average GDP growth of 8%:

Table 11: (Outdated) Container forecast Arcadis for whole Myanmar (TEU/year)

2017	2020	2023	2026	2030
520.000	630.000	750.000	870.000	1.200.000

Japan International Cooperation Agency forecast

JICA uses the GDP growth data from IMF and established a 'high case' and 'low case' scenario for Myanmar. The forecasts presented in the tables below do not only account for GDP/capita, but also for TEU/capita.

Table 12: Total cargo forecast for whole Myanmar by JICA (1000 Ton/year)

Case	2011	2015	2020	2025	2030
High case	25.696	29.607	42.999	62.221	90.000
Low case	25.696	28.321	36.689	47.417	61.300

Table 13: Container forecast for whole Myanmar by JICA (TEU/year)

Case	2011	2015	2020	2025	2030
High case	335.000	892.000	1.986.000	4.014.000	8.100.000
Low case	335.000	853.000	1.700.000	3.064.000	5.500.000

The existing share of cargo throughput in 2010 at Yangon and Thilawa port was 91.5% (JICA, 2014). Assuming this share to continue in the future, the total cargo throughput at Yangon and Thilawa will be 57 million tons per year in 2025 (91.5% of 62.221 from Table 12). The container cargo throughput in 2025 is estimated at 41 million tons, which is equivalent to 3 to 4 million TEU (approximately 11 ton/TEU). This container forecast and other commodity forecasts from JICA can be found in Table 14.

Table 14: Future cargo demand forecast for Yangon and Thilawa Port (1.000 Ton/year)

<table>
<tr><th>Port</th><th>Category</th><th>Commodity</th><th>2010</th><th>2025</th></tr>
<tr><td rowspan="7">Yangon</td><td rowspan="6">Foreign</td><td>General cargo</td><td rowspan="6">17.372</td><td>5.441</td></tr>
<tr><td>Vehicle</td><td>396</td></tr>
<tr><td>Agribulk</td><td>1.000</td></tr>
<tr><td>Petroleum</td><td>7.285</td></tr>
<tr><td>Container</td><td>41.063</td></tr>
<tr><td>Total</td><td>55.185</td></tr>
<tr><td colspan="2">Coastal</td><td>1.067</td><td>2.000</td></tr>
</table>

	Sub-total	18.439	57.185
	Others	1.718	5.036
	Total	20.157	62.221

As almost all container cargo of Myanmar is handled at Yangon and Thilawa port, for cargo forecasting it is assumed container cargo volume of other ports can be neglected. Regarding the type of commodity and containerization, Arcadis estimated future share ratio's between general cargo and container cargo based on global trends in maritime trade. Due to containerization, it is expected that the share of containers increases in the coming decades.

Table 15: Containerization trend

	2012	**2014**	**2016**	**2018**	**2020**	**2022**	**2024**	**2026**	**2028**	**2030**
General	89%	81%	73%	65%	50%	35%	30%	35%	17%	10%
Container	11%	19%	27%	35%	50%	65%	70%	75%	83%	90%
General	8.335	8.738	9.094	9.133	7.637	5.818	5.447	4.973	3.716	2.409
Container	1.043	2.066	3.384	4.944	7.637	10.806	12.709	14.918	18.141	21.683
'000 ton	9.378	10.804	12.478	14.077	15.273	16.624	18.156	19.890	21.857	24.092

Important to mention is the share of container transport which is 41.063 of 55.185 tons in Table 14. This means a container share of 75% which agrees with the containerization data and prediction for import cargo by Arcadis in Table 15.

Top-down method using country comparison

Another method to undertake top-down projection of container trade is to compare historic growth of container trade with countries which historically have been similar to Myanmar (Arcadis, 2013). Within this method, the population and economic condition of the country are considered as the key parameters to compare. Besides it is believed that having a better communication system in a country increases productivity of people in their work. Currently, Myanmar is categorized as 'lower middle income' country by the World Bank. Therefore Myanmar will be compared with other countries from this 'lower middle income' category in Asia and with population amounts in the same range as Myanmar.

Table 16: TEU and population country comparison (import and export)

	Myanmar				**Vietnam**				**Thailand**			
Year	TEU	Pop.	Mob.	Int.	TEU	Pop.	Mob.	Int.	TEU	Pop.	Mob.	Int.
1990	Million		Per 100 p.		Million		Per 100 p.		Million		Per 100 p.	
1993												
1996		43.793	0.016			73.157	0.09					
1999		45.539	0.024		1.190	76.597	0.41		3.179	62.307	3.0	
2002		47.140	0.097		1.772	79.538	2.31	0.04	3.799	64.073	27.4	2.77
2005		48.483	0.256	0.042	2.537	82.392	11.3	0.14	5.115	65.425	46.5	4.77
2008	0.180	49.480	0.718	0.02	4.394	85.119	85.7	1.11	6.726	66.546	93.4	9.23
2011	0.381	50.553	2.376	0.079	6.924	87.860	142	4.6	7.036	67.530	116	17
2014	0.717	51.924	54.0	0.501	8.150	90.729	147	11.6	8.119	68.417	144	23
2016	1.100	53.476	89.3	1.683	8.496	92.701	128	18.6	8.239	68.864	172	33
2020												
2023												
2026												
2030												

The green cells show that Myanmar is currently handling similar cargo volumes as Vietnam was handling in 1999, and the yellow cells show that the penetration of internet and mobile phones currently in Myanmar is almost equal to the penetration in Vietnam in 2008. Based on the handled TEU's, it might happen that Myanmar handles about 8 million TEU within approximately 20 years. This assumption should be handled with care because roughly four million TEU of the Vietnam volume concerns transshipment TEU in Ho Chi Minh City, which leaves about four million TEU to be handled within 20 years in Myanmar. On the other hand, Arcadis (2013) states that Myanmar is superior compared to Vietnam in terms of resources, and trade of goods which are likely to be transported in containers such as food grains, fishery products, textiles etc.

Bottom-up method using key commodities

Besides the two top-down approaches for cargo forecasting, one bottom-up method will be used. This bottom-up method starts with the key commodities and by extrapolating and summing these individual base elements, a forecast of the total throughput is made. Table 17 presents a bottom-up method carried out by JICA (2014).

Table 17: Forecast results for key commodities of Yangon Port in 2025 (JICA) in tons

		2025	
		High case	**Low case**
Import	Containers	25.108.000	19.165.000
- Non containerized:	Fuel	7.285.000	5.117.000
	Cement	1.155.000	1.072.000
	Cooking oil	250.000	250.000
	Iron material	1.202.000	991.000
	Steel products	601.000	496.000
	Cars	396.000	251.000
	General cargo	2.323.000	1.704.000
	Total	13.121.000	9.881.000
	Total	38.229.000	29.046.000
Export	Containers	15.956.000	12.180.000
- Non containerized:	Rice	1.000.000	700.000
	Total	16.956.000	12.880.000
Total		55.185.000	41.926.000
Coastal trade		2.000.000	2.000.000
Total		**57.185.000**	**43.926.000**

In Table 18 an extrapolation is carried out based on data on seaborne cargo from the Myanmar Ministry of Planning and Finance. Before comparison, it has to be noted that Table 17 are the extrapolated cargo values for Yangon International Port, while Table 18 are extrapolated values for the whole of Myanmar. Therefore it is expected that the values of Table 17 are slightly lower than the values of Table 18, although the difference will not be large because Yangon International Port handles about 90% of the total cargo of Myanmar.

Table 18: Seaborne cargo by principal commodity (Ministry of Planning and Finance, 2017)

	2012	**2013**	**2014**	**2015**	**2016**	**2025**
Grand total	21.722.343	24.167.636	24.049.913	26.075.970	31.057.188	49.235.169
Import						
Oil/lubr.	2.607.280	2.224.361	2.351.798	3.467.039	4.369.661	7.576.878
General c.	11.854.053	15.315.345	14.572.087	16.158.504	20.479.223	35.532.880
Total	14.461.333	17.539.706	16.923.885	19.625.543	24.848.884	43.109.758
Export						
Petrol oil	40.475	68.095	60.547	44.203	10.340	70.000
Rice	849.726	702.683	549.675	604.874	305.643	500.000
Minerals	55.242	25.222	8.402	1.448	5.244	10.000
Timber	1.855.418	1.441.025	1.698.044	869.562	585.422	1.000.000[1]
General C.	4.460.149	4.390.905	4.809.360	4.930.340	4.731.304	6.653.372
Total	7.261.010	6.627.930	7.126.028	6.450.427	6.208.304	8.233.372

Comparison of the forecasts from Table 17 and Table 18 leads to quite similar forecasts:

- Import: 38.229.000 ton (high case) / 29.046.000 (low case) vs. 43.109.758 ton
- Export: 16.956.000 ton (high case) / 12.180.000 (low case) vs. 8.233.372 ton
- Total: 57.185.000 ton (high case) / 43.926.000 (low case) vs. 49.235.169 ton

A total estimated cargo throughput of 50.000.000 ton is expected in 2025.

[1] Petrol oil, rice, minerals and timber are roughly estimated based on the NES export strategy, because extrapolation is not possible for these commodities.

3.2.4 (Future) trading partners

Myanmar's total exports are very limited and concentrated on a few products as mentioned in section 3.2.2. This is caused by little value-addition and weak embodiment of technology. Myanmar's trade is largely concentrated to ASEAN regions and not globalized yet. Most of Myanmar's exports are concentrated to its neighboring countries: China, India and especially Thailand (over 40% of the exports concerns Thailand). A detailed overview of Myanmar's historical (2006 – 2010) imports and exports provided by the Asian Development Bank (Ferrarini, 2013) gives a good impression of the main commodities and trading partners in Table 19 and Table 20.

Table 19: Export from Myanmar 2006 - 2010 (Ferrarini, 2013)

Importer	**Total mln. $**	**% share**	**Food %**	**Fuels %**	**Agricult. %**	**Manufact. %**
Thailand	13.615	48.4	3.3	91	4.5	0.9
India	4.722	16.8	62.8	0	36.1	1.1
China	2.891	10.3	25	3.6	67.5	4
Japan	1.538	5.6	32.7	0	7	60.3
Malaysia	812	2.9	48.1	0	43	8.8
South-Korea	532	1.9	10.9	26.8	5.1	57.2
Germany	515	1.8	2.5	0	6.9	90.6
Singapore	421	1.5	37.8	0.7	46.3	15.2
U.K.	304	1.1	30.3	0.7	2.2	66.9
Vietnam	281	1	12.8	0	85.4	1.8

Table 20: Import to Myanmar 2006 - 2010 (Ferrarini, 2013)

Exporter	**Total mln. $**	**% share**	**Food**	**Fuels**	**Agricult.**	**Manufact.**
China	10.622	35.7	3.1	5.1	1.3	90.5
Thailand	6.659	22.4	23.4	16.9	1.5	58.2
Singapore	4.677	15.7	11.6	40.3	2.4	45.7
South-Korea	1.542	5.2	0.3	1.6	5	93.1
Malaysia	1,268	4.3	39.4	15.3	3.3	42
Indonesia	1.110	3.7	58.6	0.3	0.3	40.8
India	1.005	3.4	13.2	2.2	1.9	82.7
Japan	931	3.1	0.3	0.3	1.4	97.8
Germany	232	0.8	2.4	1	1.5	95.2
Hong Kong	228	0.8	2	0.2	0.3	97.6

In order to say something about future trading partners, more recent data is needed. Table 21 presents the five most important export and import partners of Myanmar in the year 2016.

Table 21: Import and export trading partners in 2016 (World Bank, 2018)

Importer	**Trade (mln $)**	**Share (%)**	**Exporter**	**Trade (mln $)**	**Share**
China	4.767	41	*China*	5.403	34
Thailand	2.241	19	*Singapore*	2.268	15
India	1.038	9	*Thailand*	1.986	13
Singapore	891	8	*Japan*	1.255	8
Japan	663	6	*India*	1.095	7

Starting with the importing partners of Myanmar, it can be concluded that Thailand, India, China and Japan are the most important importing countries for at least 12 years. Concerning the exporting partners of Myanmar, it can be concluded that China, Singapore, Thailand are the most important exporting partners of Myanmar. Japan and India are advancing and are becoming more important as export partner. Due to lifting of sanctions and rapid economic developments in Myanmar, it is expected that international trade is expanding towards further destinations like Europe and the United States. However, during the coming years import and export will mainly be focusing on the countries mentioned in the above tables.

3.2.5 *Types and specification of ships*

The most important specification related to ships is the draught of the ship, which is directly linked to the required depth of the approach channel and port basins. One estimation of the draught which should be facilitated is given by JICA (2014). By taking into account the economic development of Myanmar, and the trends in container ship size in the world and Asian region, the country should develop ports which can accommodate container ships of 4.000 TEU such as Panamax vessels. These vessels sail on intra-Asian shipping routes, and the draught of these vessels is estimated at 13 m (50.000 DWT). This draught can also be derived from the principal dimensions of container vessels from Ligteringen & Velsink (2012), which leads to a draught of 12.5 – 13 m.

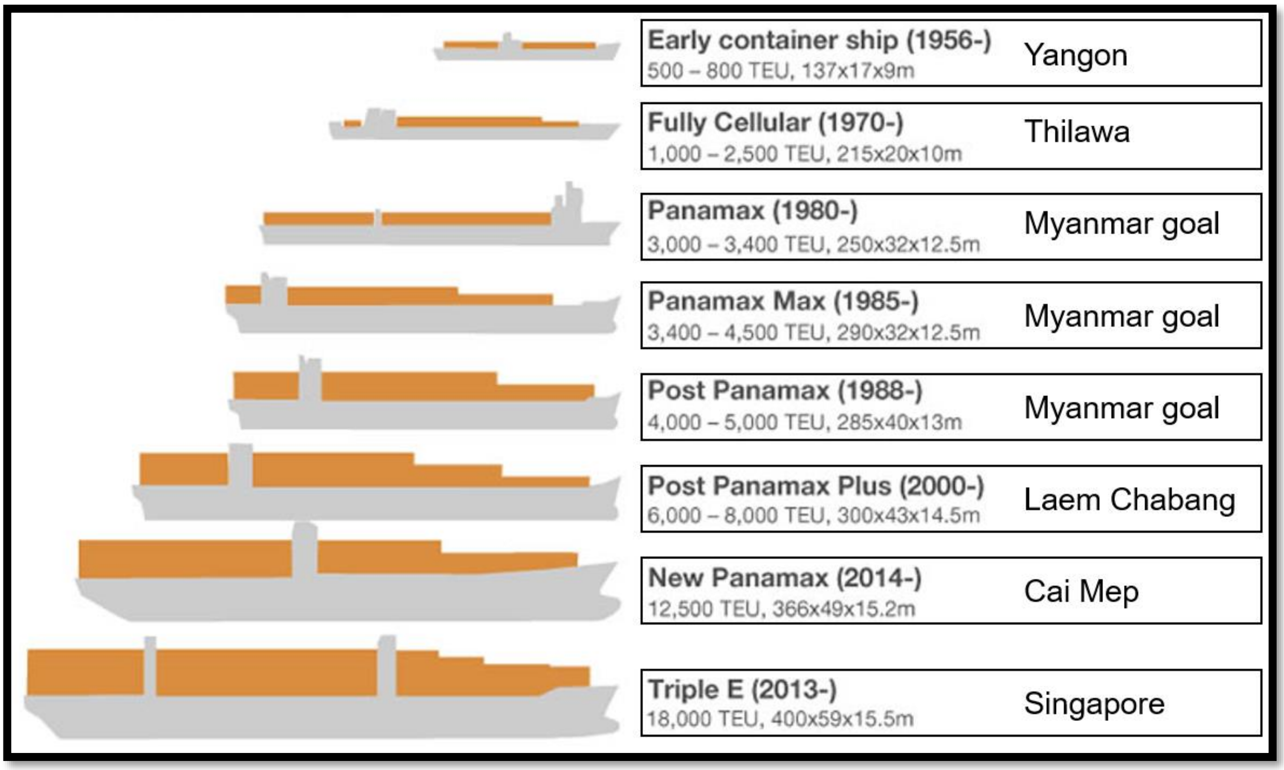


Figure 11: Maximum ship sizes for different ports (Rodrigue, 2006)

According to JICA (2014), majority of the container ships in the Asian region is about 3.000 TEU's (40.000 DWT with draughts of 12 m). Aiming at receiving this size of ships, deep container terminals are developed in Thailand (Laem Chabang), Vietnam (Cai Mep), Singapore, and Cambodia (Sihanoukville). Figure 11 shows the maximum vessel sizes for various ports. Yangon and Thilawa are able to accommodate vessels with respectively 9 and 10 m draft. The goal for new port developments in Myanmar is to accommodate Post Panamax vessels of 13 m draft. Singapore handles the largest container vessels in the region, up to 16 m draft.

Another study conducted by the ''Port and Harbour Department, Ministry of Land Infrastructure, Transport and Tourism'' titled ''Preliminary Study on National Port Development Plan in Myanmar'', emphasized the necessity of a deep sea port and concluded that the development of a deep-sea port with a depth of 14 m is needed to accommodate 3.000 – 5.000 TEU container vessels.

The functional requirement for draught of ships for this research is set at 13 m, which allows the ports to facilitate Post-Panamax vessels as suggested in the references above. Besides container vessels, also general cargo vessels, dry bulk vessels, and tanker vessels will call the ports in Myanmar. Because of the large share of container transport, the governing depths are assumed to be determined by the container vessels.

3.2.6 Coastal areas and maritime conditions

The two most important aspects to determine in this phase are the length, width and depth of the approach channel and the necessity for shelter. More detailed coastal and maritime conditions will be discussed in section 7.1.

Channel depth

The depth of approach channels depends on four factors, according to Ligteringen & Velsink (2014):

1. Draught of the ‘’design ship’’: the ship with the largest draught, which enters the port fully loaded. Larger ships may enter the port after lightering or during specific tidal levels. The design ship is mentioned in section 3.2.5.
2. The ship-related factor squat (sinkage due to ship’s speed), trim (unevenness keel due to loading conditions) and the vertical response to waves.
3. Water levels, which are mostly influenced by tidal levels however very long waves and tsunami waves should be taken into account when they occur frequently.
4. Channel bottom factors, including the variation in the dredged level and the allowance for effects of re-siltation after maintenance dredging, and the type of bottom (whether it is hard or soft)

Need for shelter

The need for shelter is determined by the limiting wave height for specific types of vessels, and the corresponding prevailing wave height at the port location. The port lay-out has to satisfy two requirements concerning wave penetration: 1.) operational conditions, and 2.) limit state conditions.

Operational conditions: the criteria at the various berth locations are given as allowable wave heights for the loading and unloading of different ships:

Table 22: Limiting wave height Hs (Ligteringen & Velsink, 2014)

Type of vessel	H_s in m (0º head or stern)	H_s in m (45º-90º beam)
General Cargo	1.0	0.8
Container, Ro/Ro ship	0.5	
Dry bulk (30.000 – 100.000 t); loading	1.5	1.0
Dry bulk (30.000 – 100.000 t); unloading	1.0	0.8 – 1.0
Tankers 30.000 t	1.5	
Tankers 30.000 t – 200.000 t	1.5 – 2.5	1.0 – 1.2
Tankers > 200.000 t	2.5 – 3.0	1.0 – 1.5

It should be noted that tankers larger than 30.000 DWT often go to offshore single buoy mooring systems. In this case, larger waves can be tolerated.

Limit state conditions: limit state conditions play a role during large wave heights. For wave heights above the operational limits in Table 22, the loading and unloading of the ship is interrupted. In ports where wave disturbance does not play a role (behind locks or riverine ports) this condition does not occur and ships can stay inside even in extreme weather. Many of the older ports, and current ports in Myanmar (mostly upriver) are examples of this protected type of ports. Most newly developed ports cannot afford to be located in natural protected areas because of navigational or constructional considerations and depth restrictions.

3.2.7 Adaptive Port Planning: uncertainty sources

As mentioned in section 2 of this report, planning under uncertainty is an important dimension of sustainable port development. Adaptive port planning incorporates uncertainty and flexibility into port planning. In order to plan ports in an adaptive way, the sources of uncertainty should be known. Within this research, four main sources can be identified. These sources have substantial uncertainties with respect to the number of containers handled, and in translation to individual product streams. Besides, a large impact on the various existing and future planned ports is expected.

1. **Economic growth scenarios**: every port development deals with uncertain economic growth scenarios, however the situation in Myanmar is even more uncertain because of the transition from a military regime towards a democratic regime.

2. **Strong competition between seaports:** as will be discussed in section 4, Yangon port handles almost all international seaborne trade, causing very little competition. Because of several (uncertain) seaport developments, Yangon port or a new seaport will experience strong competition.

3. **Lack of long-term vision:** in Myanmar, no national or individual port masterplans exist yet. This causes many uncertainties as there is no long-term vision or design for ports. Changes in throughput, commodities, or role in the national port situation can occur frequently which asks for flexible port planning.

4. **Political situation:** the political situation in Myanmar is far from stable with a conflict in the western Rakhine State. This political instability causes uncertainty for ports and ships calling to ports in this state. New political conflicts can occur in the future.

4 CASE STUDY: ANALYSIS OF MYANMAR PORTS

At this stage, the requirements and necessity for deep sea port development in Myanmar are known. In order to gain understanding of the port situation, and to gather data for development and application of the site selection framework, a comprehensive case study was carried out in Myanmar. Three months of fieldwork including interviews, desk study, and a workshop resulted in the necessary data, insights and knowledge to develop the framework (chapter 5) and apply the framework for site selection (chapter 6). This chapter deals with the results from the case study, and starts with a description of the existing ports in Myanmar, with a focus on hinterland connectivity. After the existing port situation, an overview of current deep sea port developments is presented. The last sections of this chapter deal with maritime transportation characteristics of Myanmar, and the existing site selection and deep sea port development policy. Strong emphasis is put on considerations for current deep sea port developments, as this is one of the motivations for this research.

''Myanmar is in need of good transportation of cargo with the least investment. In the past, our ports were up rivers, with inner harbors. These ports did not ask for huge investments and were relatively easy to construct. Nowadays, with the increase of the GDP, import and export, these ports will become saturated. Myanmar is in need of accommodating more import and export.'' (Chairman Myanmar Engineering Council, interview, 27-10-2017)

4.1 Existing ports

Nine main ports are located along Myanmar's coastline. Myanmar has no sea to sea transshipment ports, and the largest port is Yangon International Port, a river port which is located 32 km upstream from the mouth of the Yangon-river. This location in the Yangon-river sets restrictions to maximum ship sizes which can currently call this port. Navigation during ebb tide is difficult due to the shallowness of about 6 m at the estuary of Yangon river (JICA, 2014). Besides Yangon International Port, which is handling almost 90% of the total cargo exported and imported by Myanmar, other ports are located at: Sittwe, Kyaukphyu and Thandwe, located in Rakhine state. Pathein located in the Ayeyarwady region, and Mawlamyine located in the Mon state. Lastly, the ports of Dawei, Myeik and Kawthoung are located in the Tanintharyi region.

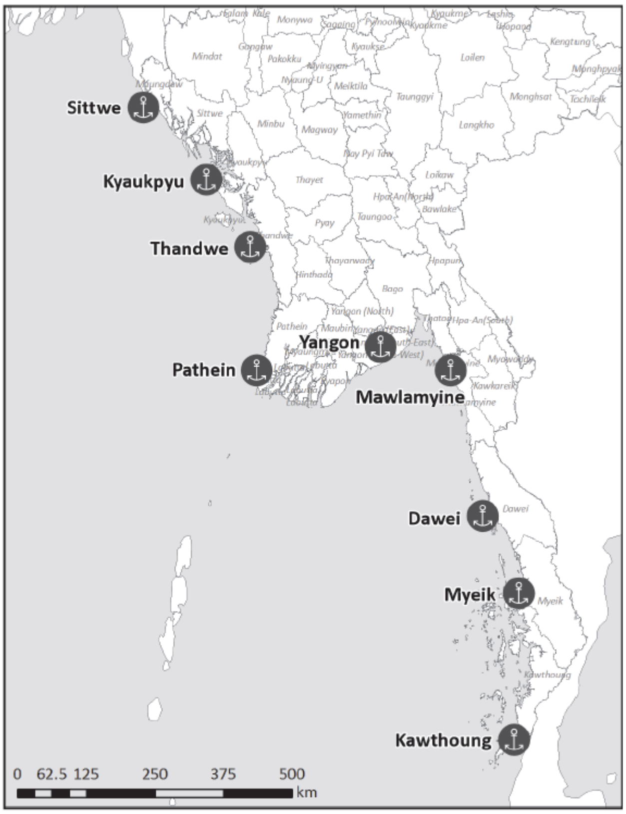


Figure 12: Existing main ports in Myanmar (JICA, 2017)

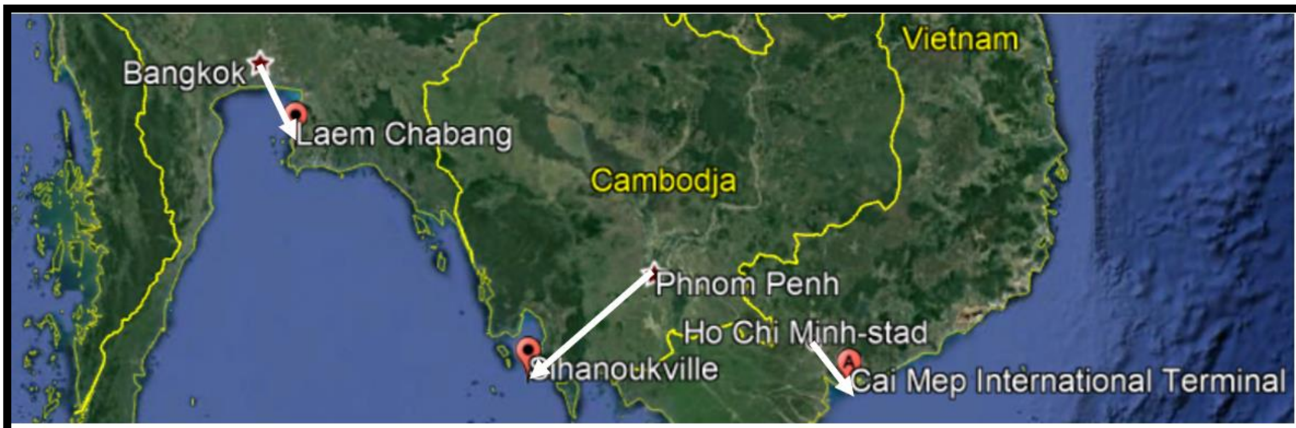
Another division can be made based on the type of port. The ports of Sittwe, Pathein, Mawlamyine and Myeik serve as international exporting ports, while the ports of Kyaukphyu, Thandwe, and Dawei mainly serve for domestic coastal traffic. Kawthoung port has been used for domestic coastal traffic as well as an export port for cargoes destined to Thailand (Dutch Maritime Network, 2016). Yangon port is the only importing and exporting international port. As the largest existing port complex, it can serve vessels up to 15.000 – 20.000 dwt, with works underway to increase up to a 35.000 dwt vessel capacity. Thilawa International Port, an expansion of the Port of Yangon, is located 16 km from Yangon downstream of the river.

Table 23 and Table 24 provide a short description of every port concerning the most important characteristics of every port (JICA, 2017). It can be concluded from Table 23 that seven out of nine existing ports are riverports, and all ports haven maximum depths between 5 – 7 m. These two characteristics are bottlenecks for deep sea port development at existing locations, because of limited water depth and limited space. Therefore new locations in the proximity of existing ports should be investigated with larger water depths. Remote ports such as Myeik and Kawthoung handle more cargo than ports closer to Yangon. Due to insufficient land transport network, the role of marine transportation is important for the lives of rural residents.

Table 23: Description and characteristics of existing ports in Myanmar

Port	Type	Cargo	Depth	Berths	Throughp. (2011)
Sittwe	- International - Riverport		5 m	3 jetties	181.000 ton
Kyaukpyu	- Domestic - Seaport	- Fish - General cargo	16 m	4 jetties	294.000 ton
Thandwe	- Domestic - Seaport	- Fuel/oil - Fish	7 m	2 jetties	33.000 ton
Pathein	- International - Riverport	- Rice (gen. cargo) - Fish	6 m	9 pontoons 1 jetty	48.000 ton
Yangon	- International - Riverport	- Containers - General cargo - Ro/Ro	10 m	6 cont./MP terminals	20.100.000 ton
Mawlamyine	- International - Riverport	- Foods/daily goods - Construct. Material	4.5 m	8 jetties 2 piers	150.000 ton
Dawei	- Domestic - Riverport	- Fish/sugar/palm - Cement	5 m	9 jetties	532.000 ton
Myeik	- International - Riverport	- Fish/oil - Rubber/lumber	6 m	4 jetties	1.140.000 ton
Kawthoung	- Domestic/Thai - Riverport	- Cement/fuel - General cargo	5 m	1 Pier small jetty	1.600.000 ton

As stated, seven out of nine ports are river ports with small natural depths, not suited to accommodate large (Post-Panamax) vessels. It is interesting to show how surrounding countries coped with this same problem. Figure 13 shows the situation in Thailand, Cambodia and Vietnam. The capitals Bangkok, Phnom Penh and Ho Chi Minh City all possess a river port far up river near the city centre. Because of navigational problems, the main deep sea ports of these countries are situated further downstream in Laem Chabang, Sihanoukville and Cai Mep. This can also be a good solution for Myanmar, with a river port in the city center of Yangon, and a deep sea port at a location with larger natural water depths.



River port **Bangkok** to deep sea port **Laem Chabang**: ± 200 km
River port **Phnom Penh** to deep sea port **Sihanoukville**: ± 100 km
River port **Ho Chi Minh City** to deep sea port **Cai Mep**: ± 50 km

Figure 13: River port - deep sea port combination in Thailand, Cambodia and Vietnam

Similar port combinations can be found in Europe. Duisburg Port (Duisport) is the world's largest inland port located in the heart of Europe's largest consumer market with more than 30 million consumers over a radius of 150 kilometers. It is located approximately 250 km inland from the port of Rotterdam, has 400 combined transport connections. Besides, it is located nearby 5 highways and handles 20.000 ships and 25.000 trains each year. The water depth is ideally suited for river-sea vessels with a loading capacity of up to 6.000 t, which is equivalent to 500 TEU ships (Duisport, 2018). Large vessels unload their cargo at Rotterdam and Antwerp and smaller river-sea vessels transship the cargo further inland towards for example Duisport. From here, the hinterland of Duisburg is served by means of inland water transport, rail or road transport. This situation can be considered in Myanmar as well. Main gateway ports which are not located directly in the proximity of Yangon handle the large sea-going vessels and river-sea vessels or coasters use a nautical connection between the main gateway port and the large inland port of Yangon (similar to Duisport).

Table 24 shows three existing ports which have road, rail, and waterway connections. Only Yangon and Pathein are connected by waterway with important hinterland areas near the capital of Nay Pyi Taw and the second largest city Mandalay, which can be seen in Figure 14.

Table 24: Hinterland connectivity and additional information

Port	Road	Rail	Waterway	Additional information
Sittwe	Yes	No	Yes	- Closest located to Bangladesh and India. - India assists to develop Sittwe as gateway port.
Kyaukpyu	Yes	No	No	- Since 2015 used for large Chinese oil tankers. - Possesses large natural water depths of 20 m.
Thandwe	Yes	No	No	- Monthly fuel tanker service from Yangon to Thandwe. - 3 times per month fish transport to Thandwe town.
Pathein	**Yes**	**Yes**	**Yes**	- 71 miles distance to the Pathein river mouth - Daily service between Yangon and Pathein.
Yangon	**Yes**	**Yes**	**Yes**	- Separated in Yangon and Thilawa area - Handles ± 90% of all Myanmar cargo
Mawlamyine	**Yes**	**Yes**	**Yes**	- Cargo is handled manually without equipment - Large sedimentation problems in Thanlwin River
Dawei	Yes	Yes	No	- Large sedimentation problems at river mouth - No mechanical handling of cargo
Myeik	Yes	No	No	- Major problem is shallowness of the channel - Handles about 100 TEU/month
Kawthoung	Yes	No	No	- Directly connected with Thailand by a river - Most southern point of Myanmar

Summarized, Myanmar's port situation is characterized by one main gateway port in Yangon, to which almost all international traffic is directed, and eight small ports to which some coastal traffic is carried out. The smaller ports mainly serve as fishery port and distribution of cargo for a small local hinterland. Except for some part of Yangon port, handling equipment is heavily outdated and most ports are not capable of handling containers.

Competition between ports

When it comes to competition among the existing ports in Myanmar, the port of Yangon has a monopoly presently due to its relatively better infrastructure, connectivity and support of rich hinterland and large population. However, in future situations this scenario may change when developments and investments are being channeled to other regions in Myanmar.

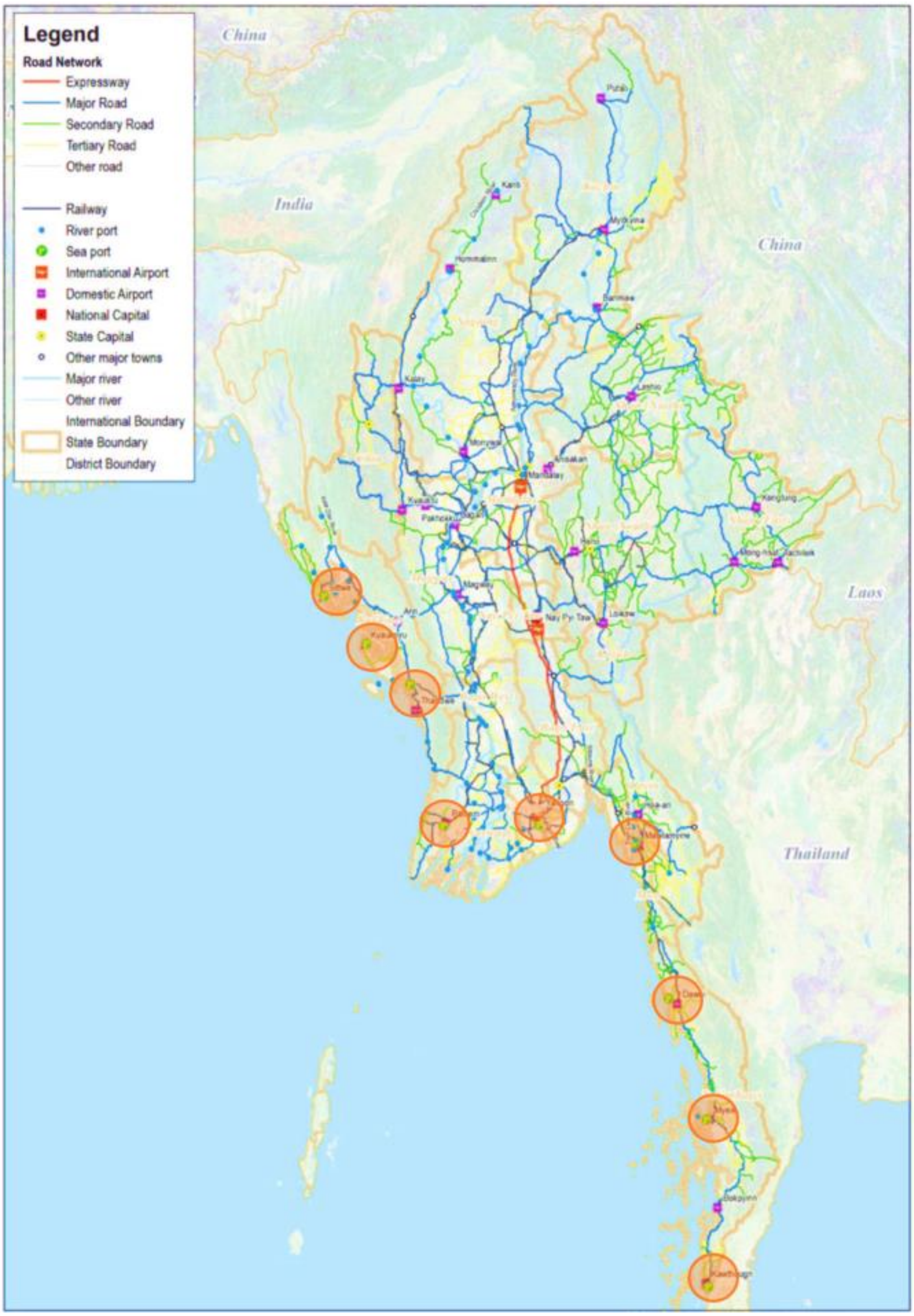


Figure 14: Overview of existing infrastructure in Myanmar (JICA, 2017)

For a port, the hinterland is the most important requirement for success as this is the location of both production and consumption. As can be seen in Figure 14, the ports at the West coast Sittwe, Kyaukpyu and Thandwe are closer to the hinterland compared to Yangon, but have very bad hinterland connections. Pathein and Mawlamyine are almost equidistant to the hinterland compared to Yangon. As Yangon has superior infrastructure and connectivity compared to other ports, it has become the main gateway port to Myanmar. In addition to the five mentioned ports, three ports are located on the southern strip of land bordering Thailand. These three ports lack basic infrastructure and connectivity and are located far away from the main hinterland. Most of the plans for infrastructural development are situated in the central regions of Myanmar and around Yangon (JICA, 2017). The North-Western states with Sittwe, Kyaukpyu and Thandwe are not expected to develop its connection by road and railways in the nearby future.

According to Arcadis (2013), three factors play a decisive role in attracting cargo to a port over its competitors:

- Infrastructure at port
- Connectivity to the hinterland
- Distance to the hinterland

The distance of the hinterland with the port defines the inland cost of moving cargo from the port to the hinterland. Based on the cost and other parameters, the competitive advantage of the port could be established. In the case of Myanmar, where infrastructure is underdeveloped, the distance of the hinterland has to be coupled with the quality of the connecting infrastructure.

4.1.1 *Port infrastructure and hinterland connectivity*

One of the biggest development challenges is Myanmar's infrastructure and connectivity, with an estimated $120 billion infrastructure gap for 2017 - 2030. Myanmar's inadequate infrastructure hinders access to markets and social services and increases transport costs. This slows down the business environment, and is a main cause of poverty and regional inequality. Only 40% of Myanmar's road network is paved, and 20 million people lacks access to all-weather roads, while inland waterway and river port infrastructure is also inadequate (Asian Development Bank, 2017). Due to many decades of infrastructure underinvestment, transportation and logistics costs are high in Myanmar. Myanmar ranks lowest in the ASEAN region in quality of logistics infrastructure (Asian Development Bank, 2014), however the country's main rivers offer potentially cheap internal transport.

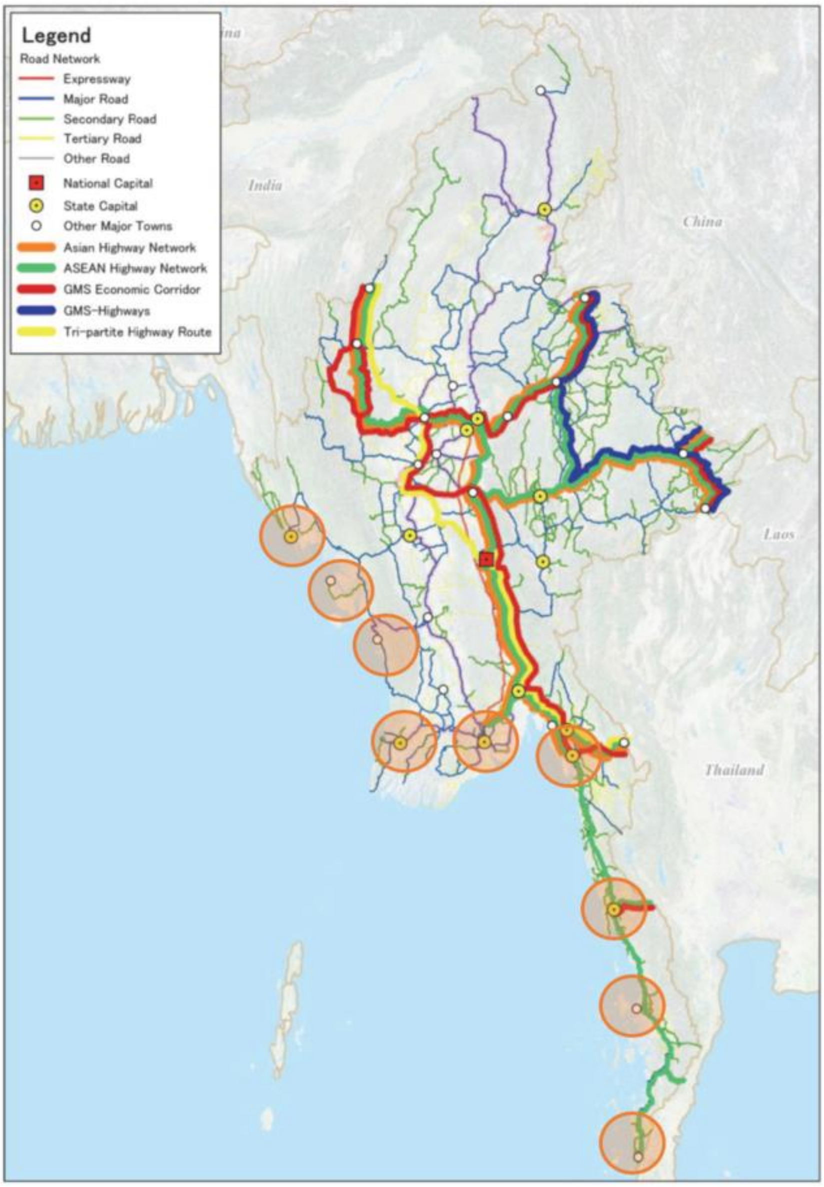


Figure 15: Myanmar's road infrastructure network (JICA, 2017)

Yangon port has the most effective connectivity in the region. Waterways connecting to the northern region of Myanmar provide faster and cost effective way for inland movement of cargo. Due to existing infrastructure for inland movement of cargo and a dominant consumer base population, Yangon is likely to remain the most prominent gateway to Myanmar. Yangon does not always offer the shortest distance to the hinterland. However, distance is not the only important aspect of the hinterland connection. In an underdeveloped country like Myanmar the physical condition of the hinterland connections is important as well. Many roads are not suited for fast movement of cargo. Furthermore, for long distance movement of cargo, rail or inland waterways are preferred due to an economy of scale which reduces the unit cost of transportation. Table 25 provides an overview of distances and travel times by road to the important hinterland destination Mandalay, and border passings at India, China and Thailand. It can be concluded that Yangon has a central location, and offers fast (which does not always mean the shortest) road connections with hinterland destinations, mainly because of the only existing expressway between Yangon and Mandalay. For a gateway port, these fast and proper hinterland connections are of vital importance for distribution of goods.

Table 25: Distances to key hinterland destinations

	Mandalay	**Myitkyina**	**Muse**	**Mae Sot**	**Tamu**
	Myanmar	Myanmar	China	Thailand	India
Sittwe	782 (16 hr.)	1294 (28 hr.)	1229 (27 hr.)	1256 (25 hr.)	1055 (23 hr.)
Kyauk Phyu	655 (13 hr.)	1166 (25 hr.)	1101 (24 hr.)	1129 (22 hr.)	928 (20 hr.)
Pathein	807 (12 hr.)	1365 (23 hr.)	1254 (23 hr.)	623 (13 hr.)	1058 (20 hr.)
Yangon	**626 (8 hr.)**	**1184 (20 hr.)**	**1073 (19 hr.)**	442 (10 hr.)	**1070 (17 hr.)**
Mawlamyine	756 (11 hr.)	1314 (22 hr.)	1203 (22 hr.)	**181 (5 hr.)**	1201 (20 hr.)
Dawei	1064 (16 hr.)	1621 (28 hr.)	1510 (27 hr.)	489 (10 hr.)	1508 (25 hr.)

4.2 Current developments of deep sea ports

Myanmar is currently characterized by a dynamic port development situation. Several deep sea port developments are going on, and the six (four deep sea port projects, two riverine port expansions in Yangon and Thilawa) most promising ones are presented in Figure 16 (TEU = Twenty Foot Equivalent Unit, SEZ = Special Economic Zone, EIA = Environmental Impact Assessment) and will be elaborated upon in Appendix E. The current developments take place at locations which are also mentioned in Figure 12. The developments at Yangon, Kyaukpyu, Pathein, Thilawa, Kalegauk and Dawei received the most attention during the case study and were ranked most promising during the workshop on port development.

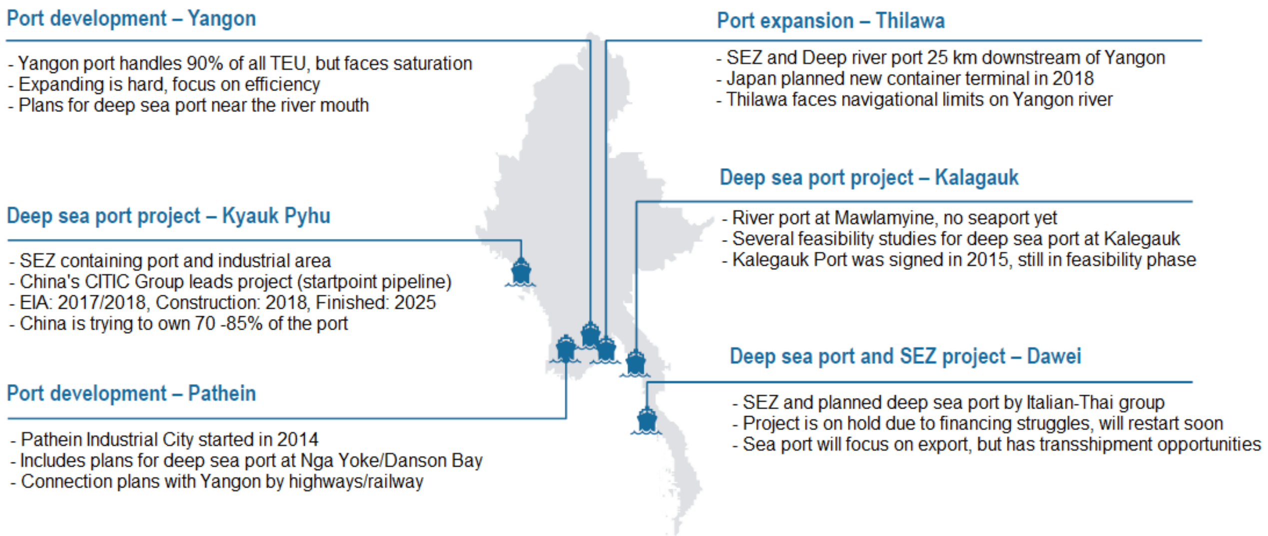


Figure 16: Six current deep sea port developments

The strategic objectives for maritime developments are formulated in the Transport Masterplan (JICA, 2017) as follows:

1. Enhance port capacity of Yangon port (including Thilawa area) to meet sharply increasing cargo demands and to reduce dwelling time of cargoes and ships in the port.
2. Develop a deep seaport that can accommodate mother vessels in trunk routes to support the further increasing import and export of goods, at reasonable cost to users in the Central North-South road corridor.
3. Formulate a port masterplan for each seaport and their hinterlands.
4. Invest in effective and efficient port management.

With respect to the second strategic objective, it is not stated at which location the deep sea port (expected to be the main gateway to Myanmar) has to be developed. However, during the case study it became clear that there is large pressure to make sure that Yangon remains the main gateway and that Yangon will be the region for development of a deep sea port in the nearby future.

4.3 Myanmar's strategic maritime location

Myanmar is located strategically in the global maritime network, and in between almost half of the world's population. This section elaborates shortly on the possibilities for Myanmar as transshipment hub in the region due to its strategic location, and the location near the world's most important shipping routes.

4.3.1 Sea to sea transshipment

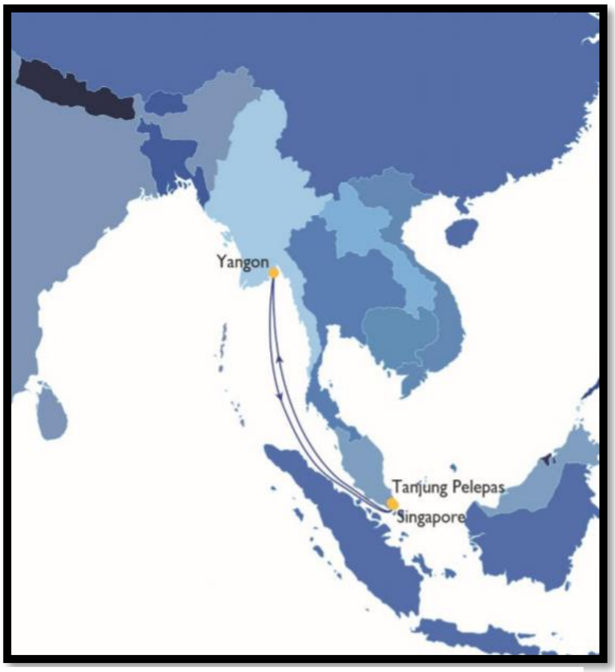


Figure 17: Yangon feeder services

Currently, the transport market in Myanmar with regard to sea-going vessels can be characterized as a feeder market, in which feeder vessels of approximately 1000 – 1200 TEU are being loaded at main hubs in Singapore, Port Klang and Tanjung Pelepas as shown in Figure 17, and unloaded in Yangon port or Thilawa port (and vice versa are being loaded at Yangon and unloaded at larger hubs). In this way the smaller feeder vessels 'feed' the big container vessels. Reasons for occurrence of a feeder market in Myanmar are twofold: on the one hand because there is too little volume to attract bigger vessels, but on the other hand because the morphological situation and water depths in the Yangon river do not allow for vessels with larger draughts (Chief Financial Officer MIP, interview, 31-10-2017). For example, a weekly feeder service between Singapore, Tanjung Pelepas in Malaysia and Yangon is operating.

It is most likely that Myanmar remains a feeder market in the near future because competition with Singapore and Port Klang is not possible yet. These transshipment hubs have large economies of scale as can be seen in Table 26. As interviewee 10 (Head of Transportation Arcadis Asia, interview, 17-11-2017) puts it, to compete as transshipment hub in this highly competitive region, Myanmar should handle at least 3-4 mln TEU/year. Shipping lines tranship at ports which help to lower their operating cost, and larger and more experienced port operators simply tranship cheaper. Another factor which influences the choice of hub, is the distance from the main shipping routes. Singapore and Malaysia are located on the circum-equatorial shipping route, while Myanmar is located off this route.

Table 26: TEU volumes Yangon, Singapore and Port Klang (x 1.000 TEU)

	2011	2012	2013	2014	2015	2016
Yangon	413	478	614	745	893	1.059
Singapore	29.938	31.649	32.579	34.688	31.710	31.688
Port Klang	6.089	6.307	6.582	7.041	7.932	9.067

Yangon, or Myanmar in wider perspective, is most likely to remain a feeder market in the near future, however a relatively small increase in deployed feeder vessel size can yield a significant decrease in logistics cost and an increase in economic benefit. Average price for an import container (Singapore → Yangon) is $600 and average price for an export container (Yangon → Singapore) is $300. According to the shipping lines serving Yangon and Thilawa port, assuming a maximum draught of 11 m, the largest deployed feeder handles 2.000 TEU (JICA, 2014). According to the cargo forecast in section 3.2.3, TEU demand forecast increases at least 10% each year (VDB Loi, 2017), it is most likely these 2.000 TEU vessels will be fully loaded. Table 27 shows the currently deployed feeder vessels (YG = Yangon, PK = Port Klang, SP = Port of Sinapore), and assuming shipping lines increase their feeders from ±1.000 TEU to 2.000 TEU, the net increase of the loading capacity is 1.000 TEU.

Table 27: Deployed feeder vessels (JICA, 2014)

	Shipping Line	Max. TEU	Route
1.	ACL	907	YG-PK-SP
2.	MFSL	502	YG-PK-SP
3.	CSCL	1.118	YG-PK-TP-SP
4.	Samudera	1.118	YG-PK-SP
5.	RCL & MOL	628	YG-SP
6.	IAL	618	YG-PK
7.	KMA	684	YG-PK-SP
8.	TS	954	YG-PK-SP
9.	Jindal	671	YG-PK

Producing (1 x 1.000 TEU x $300 + 1 x 1.000 TEU x $600) $900.000 revenues. Part of these revenues can be used by shipping lines to reduce the ocean freight level, being more competitive, and encourage trade activities to and from Myanmar. According to a major shipping line (YG-SP), the current feeder size of 1.000 TEU is a bottleneck in the Singapore-Myanmar route. Especially import cargo is heavily stagnated, and 2.000 TEU vessels could double the throughput (JICA, 2014).

4.3.2 Strait of Malacca & corridor-based road network

One of the most important drivers for future maritime potential of Myanmar is the fact that Myanmar can provide transportation alternatives for the Strait of Malacca, by a comprehensive corridor-based road network in the Greater Mekong Subregion (GMS). The GMS is composed of Cambodia, Lao PDR, Myanmar, Vietnam, Thailand, Yunnan province, and the Guangxi Autonomous Region of China. This region has seen remarkable progress in the development of cross-border transport infrastructure along its ''economic corridors'' (Figure 18) Its significance lies in the corridor's contribution to higher regional economic growth through promotion of intra-regional trade and investments than would be possible through the independent efforts of national investment projects alone (Fujimura, 2017).

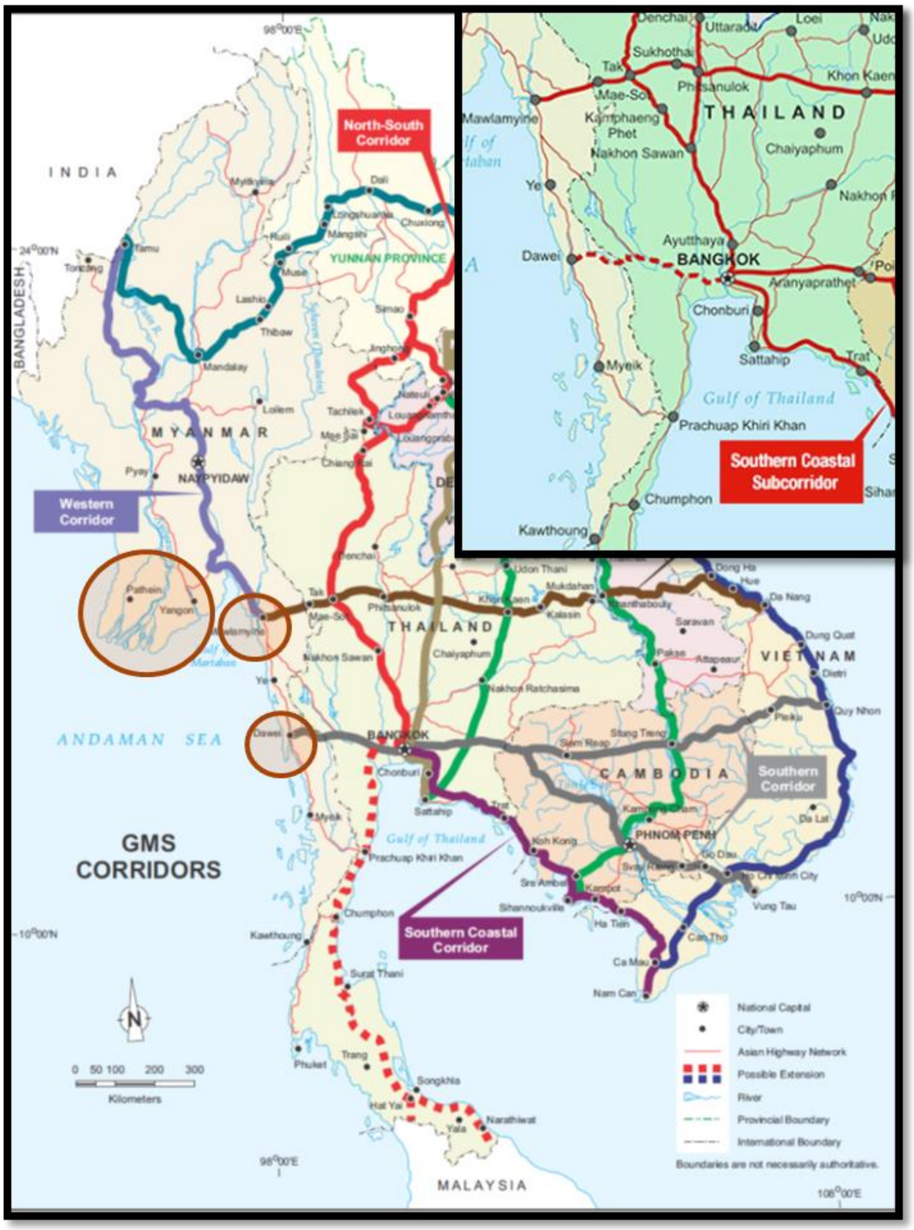


Figure 18: Corridors in the GMS (ADB, 2017), inserted figure (304 Industrial Park, 2016)

Myanmar has the potential to become a prime transportation hub in Asia and to serve as the main gateway between South Asia, Southeast Asia, and East Asia. Various bilateral and multilateral programs are developing transport links to take advantage of Myanmar's 2.800-kilometer coastline with access through the Bay of Bengal and major inland waterways. Physical connectivity with Myanmar's coastline and the Indian Ocean has become a priority for Myanmar's neighbors. Their primary objective is to establish alternative routes to reduce their dependency on the

Strait of Malacca (Florento & Corpuz, 2014). As a result, Myanmar's infrastructure program is also focused on constructing deep sea ports and on strengthening north-south connectivity via roads, railways, and inland waterways. An important corridor is the completed East-West Economic Corridor (EWEC). This expressway is linking the city of Mawlamyine in Myanmar with Thailand, Laos, Cambodia with the city of Da Nang in Vietnam. This corridor opens access to markets for Myanmar and by using EWEC, the travel time between Bangkok and Yangon is reduced to three days, compared with three weeks when using marine transport via the Straits of Malacca. Another important corridor is the southern corridor from Dawei to Bangkok, although some sources (304 Industrial Park, 2016) state this corridor cannot be used yet.

One of the proposed deep sea port projects which plays a role in this infrastructure program is Dawei SEZ. This proposed deep sea port with industrial zone is located at the far western end of the southern corridor in Figure 18. Dawei SEZ connects directly with Thailand by the Southern corridor, and a rail link from Dawei-Yangon-Mandalay-Muse towards China is under evaluation. Dawei port will have an important role in promoting regional economic integration, and aims at (Florento & Corpuz, 2014):

- Reduce logistics and labor costs for GMS members by providing an alternative sea route to India, China, Middle-East, Europe and Africa
- Reduce dependence on the congested Strait of Malacca
- Provide an industrial location so that private firms and factories in Thailand and other neighboring countries may consider relocating
- Supporting Myanmar's strategic importance as a regional logistic and trading hub

Another deep sea port project which can act as alternative for the Strait of Malacca is Kyaukpyu at the Northwestern coast of Myanmar in Rakhine State, developed by a Chinese firm. The 900-km long Malacca Strait links Asia with the Middle East and Europe, carrying about 40 percent of the world's trade. Approximately 80 percent of China's crude oil imports from the Middle East and Africa are passing the street of Malacca, which causes the narrow and congested Strait of Malacca to become increasingly important for Beijing (Reuters, 2018). China tries to avoid Malacca by transporting their crude oil directly from Myanmar towards China by means of pipelines. Figure 19 shows the major shipping choke point around Malaysia and Singapore.

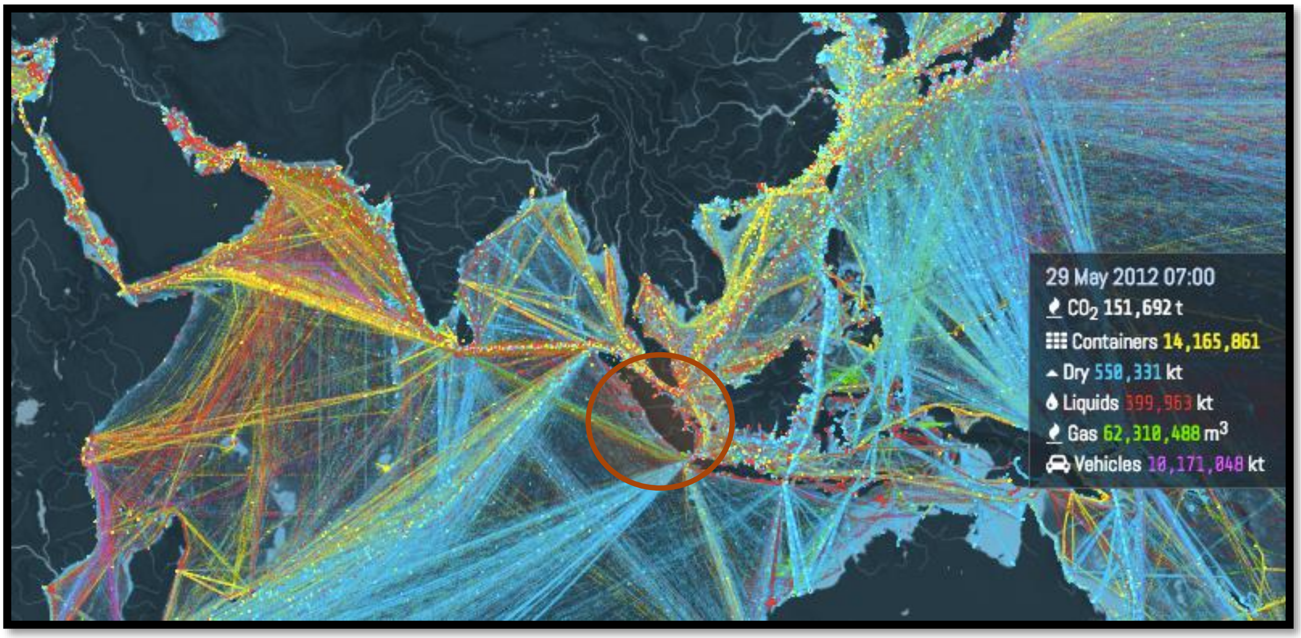


Figure 19: Shipping activities around the congested street of Malacca (Kiln, 2018)

More than 50.000 merchant ships pass this waterway every year, and because of its narrowest point of 2.7 km creating a bottleneck and potential for collisions, opportunities arise for alternatives in Myanmar. A Senior Engineer from the National Engineering & Planning Services (19-10-2017) thinks deep sea port development on the southeastern coast of Myanmar (e.g. Mawlamyine) can serve as an alternative for the port of Singapore, and these developments also strengthen the competitive position of Myanmar as vessels are no longer forced into the Strait of Malacca. Competition with port of Singapore is doubted, however in the very long term this may be possible.

4.4 National port development policy

Port development policy in Myanmar is a rather vaguely described subject which is present in many different development plans. Besides, Myanmar stands at the beginning of formulating new laws and regulations for all government departments. As stated in the Logistics Masterplan by JICA and the Ministry of Transport and Communications (2017), it is common throughout the world for a port area to be managed by the public sector, based on the principle that the water area of a country (with the exception of privately owned water areas), should be used for the public interest. National governments are responsible for formulating the basic direction of the port development, and subsequently the port management should formulate detailed port planning which confirms with the 'basic direction'. A nationwide port development policy does not exist at present in Myanmar. A new 'Port Act' was formulated in April 2015 in Myanmar, in which no concept of public water area management system is regulated. Therefore it is not possible for the private sector to develop and utilize the public water area, except in cases in which the private sector owns the land in front of the water area.

During stakeholder consultations and desk study, it became clear that port development policy is not laid down in a single development plan, and many stakeholders were unable to specify the governing body concerning port development and site selection. This section aims at pointing out port development policy which elaborate upon site selection criteria in Myanmar (section 4.4.3), which may be incorporated in the site selection framework in chapter 5. However, as port development policy is unclear and underdeveloped in Myanmar, the framework will mainly be based on own insights and knowledge gained from the case study.

4.4.1 Port development & masterplans

Even more important than the lack of possibilities for the private sector to develop the public water area, is the absence of a clause in the ''Port Act'' which requires establishment of a nation-wide port location plan and the necessary functions, capacities and connections of ports from a national point of view. This problem is clearly formulated by JICA as: *''Consequently, the port development within a port limit is conducted by private companies in a disorderly manner, which prevents the well-balanced development of nationwide ports. In order to prevent this situation described above from occurring and to make effective use of public water areas, it is necessary to amend the ''Port Act''. Based on this amendment, the national government should establish a ''Basic Port Development Policy, Port Location Plan, and Port Layout Plan'' to materialize well-balanced national land development.''* (JICA, 2017)

Gaining understanding of national port development policy is complex, because of the large amount of separate development plans in which port development is mentioned. There is no national port development plan which causes that all information, and visions from the government should be extracted from the separate development plans. The following development plans are currently active in Myanmar (presented in the order of year prepared):

1. National Comprehensive Development Master Plan (NCDP)
2. Agriculture Development Policies
3. Industrial Policy Paper
4. National Spatial Development Plan (NSDP)
5. National Transport Master Plan (MYT)
6. Myanmar Industrial Development Visions (MIDV)
7. National Export Strategies (NES)
8. 12 New National Economic Policies

A stakeholder consultation with the Director General of Myanmar Port Authority (Interviewee 12, 21-11-2017) clarified that there are three ways of initiating a port development in Myanmar:

1. Port development according to the Constitution Law 2008 and the Myanmar Port Authority Law 2015 (Myanma Port Authority, 2015):
   Chapter 3, 5a: ''*The ministry, with approval of the Union Government may determine the port limit, by notification, by demarcating the ports, out-ports, main port and deep sea ports at the suitable places within the State for the berthing of sea-going vessels, coastal and inland-going vessels.''* Unfortunately the definition of 'suitable places' is not given in the MPA Law 2015.
   Chapter 4, 8a: ''*The Ministry, with the approval of the Union Government may permit the local and foreign investors to operate the works of exploration of new places for port and building, upgrade, extension and*

maintenance by any means for the development of ports by concluding the contract with the Myanma Port Authority and by stipulating the terms and conditions.''

2. By means of higher level stakeholders, appointed by the Union Government: Dawei Special Economic Zone committee, Kyaukpyu Special Economic Zone Committee. These national level committees provide their own port development policies and are headed by the vice-president. The committees have to carry out a concession agreement with Myanmar Port Authority.
3. A third way of port development is by means of a Memorandum of Understanding (MoU). For example, a MoU was signed between China and Myanmar. Under this MoU, in cooperation with the Ministry of Energy, an oil terminal is built at Kyaukpyu.

Interviewee 12 (21-11-2017) stated that the government laid down the ''12-point economic policy'', of which one pillar concerns giving high priority to infrastructure development, and one pillar concerns encouraging foreign investment in Myanmar. Foreign investors may ask permission for deep sea port developments to the Directorate of Investment and Company Administration (DICA) and the Myanmar Investment Commission (MIC). However, permission is also needed from the national government because deep sea port developments are national level decisions. It is possible that a tender process will be carried out, after approval of the proposal. The first step of the deep sea port development, and the most important selection criteria, is finding potential locations with suitable large water depths. Afterwards a proposal can be submitted to carry out a feasibility study.

VDB Loi, a network of law and tax advisory firms with offices in Cambodia, Indonesia, Laos, Myanmar and Vietnam, state that the ports in Myanmar are regulated by MPA, and that activities of MPA are governed by the Myanmar Port Authority Law 2015 and the 2016 Myanmar Port Authority Rules. According to VDB Loi (2017), the following three ways for the private sector exist to develop an international port terminal:

1. National Development Plan: the MPA has a development plan for the development of new ports and terminals and will eventually decide to tender out the development of such to private investors.
2. Unsolicited proposals: the private sector may identify a port project and submit an unsolicited proposal to the MPA. Depending on the quality of the proposal, the MPA may decide to appoint the investor directly or to tender the project out, after approval from the Union Government has been secured for the project.
3. Private ports: an investor may develop a private port for its own purpose and by securing its own land. This will still require to obtain MPA licensing as international port services are under MPA jurisdiction and royalty fees to the MPA will be due.

For completeness, the complete port development policy is depicted in Figure 20.

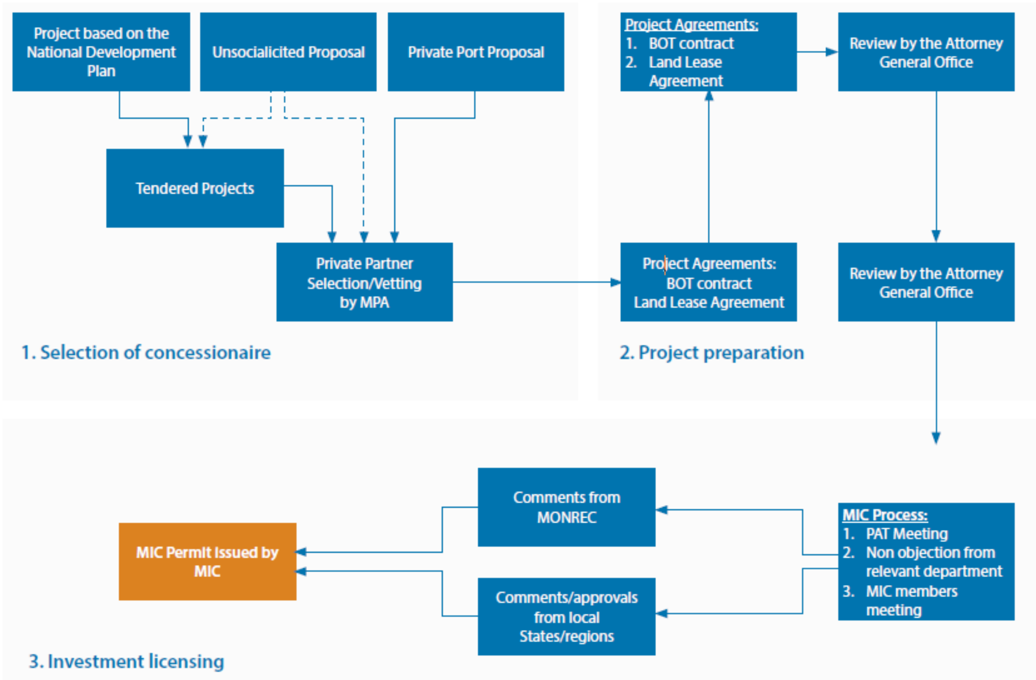


Figure 20: Port development policy in Myanmar (VDB Loi, 2017)

4.4.2 Site selection: influence of neighboring countries

The beforementioned occurrence of port development in national policy does not elaborate specific on site selection methodology or on site selection criteria. During the case study, two possible explanations for selecting sites of deep sea port developments came forward:

- Influence of neighboring countries China, Thailand, India (section 4.4.2)
- Special Economic Zones determined during old regime (section 4.4.3)

Myanmar encourages foreign investments because it is not able to finance all infrastructural projects themselves. With investments from the World Bank, Asian Development Bank, private parties, and loans from other countries, infrastructural projects can be realized. Myanmar is working on deep sea port projects with neighboring countries India, China, and Thailand. These countries try to allow direct access to the Bay of Bengal for their land-locked regions. The North Eastern states of India, South West China and parts of Western Thailand could be accessed using sea and land route or via Myanmar. Currently, Yangon port is acting as the main gateway to Myanmar. However, the location of Yangon port is not suitable to act as gateway to India, China or Thailand (Arcadis, 2013). Therefore, all three countries are planning to develop separate infrastructure focused on catering to their country's needs:

- India is developing Sittwe port on the western part of Myanmar
- China is developing Kyauk Phyu port to the south of Sittwe port
- Thailand is developing Dawei port at the southern part of Myanmar

All of these ports are planned with a specific mandate to act as a gateway to the investing country. As Myanmar emerges from decades of economic and political isolation, the government is pinning Myanmar's future on foreign capital and technology to finance and develop special economic zones and deep sea ports. However, Myanmar should aim at receiving fair stakes during the lifetime of the project, to make sure Myanmar earns part of the revenues when shippers choose to use the Indian, Chinese and Thai ports. As interviewee 3 (27-10-2017) stated, Myanmar does not know which deep sea port location is best, as all current project are introduced, owned and executed by foreign parties. Myanmar needs a deep sea port for its own revenues. Interviewee 7 (10-11-2017) agrees with the large foreign influence, however adds that this is the working practice in those countries, and they just donate money or grant soft loans so it is very attractive for Myanmar to accept these projects.

India – Sittwe

In 2008, the Indian government signed an agreement with the Myanmar government to construct the Kaladan Multi-Modal Transit Transport Project. This project will connect the Kolkata port in India with Sittwe port in Myanmar. It can link Myanmar and India by road and inland water transport. The project is divided in three phases: Sittwe port development, 158 km dredging of the Kaladan river, and construction of a 129 km highway (JICA, 2017). According to Arcadis (2013), the main purpose of this port development is to provide an export- and import trade route for the northern part of India, and connectivity enhancement to other Asian or international markets through this development is highly improbable.

China – Kyaukpyu

The main purpose of the port is to function as a gateway port for China's oil from the Middle East and as a port for natural gas from Bengal Bay (JICA, 2017 & Arcadis, 2013). The pipeline for transport of oil towards Yunnan province in China is reportedly capable of transporting 12 billion cubic meter per annum. According to Reuters (2017), China is looking to take a stake of up to 85 percent in a strategically important sea port in Myanmar. Beijing has been pushing for preferential access to the deep sea port of Kyaukpyu on the Bay of Bengal, as part of its ambitious ''One Belt, One Road'' infrastructure investment plan to deepen its links with economies throughout Asia and beyond.

Thailand – Dawei

The deep sea port at Dawei is expected to be the gateway of the Southern Economic Corridor of the GMS, but is a high priority for the government (JICA, 2017). The project was set on hold due to financing problems, and Thailand has been roping in other countries for financial assistance. The budget for construction of highway to and from Thailand's border is provided by a Thai low-interest loan. The original project started in 2008, however never took off due to the large scale of the project. Construction is expected to start in 2018 (Reuters, 2017)

4.4.3 *Site selection: Special Economic Zones*

A Special Economic Zone (SEZ) is a delineated geographical area with a special legal regime for business activity. Many Southeast Asian countries have adopted SEZ's, which typically involve major investments in infrastructure and demand large amounts of land. Proponents say that SEZ's facilitate rapid economic development by creating investment activities, while opponents say their economic success has been mixed and SEZ's are often accompanied by social and environmental issues like resettlements and loss of nature, both in Myanmar and elsewhere in South-East Asia. The initiation for establishment of the SEZ's in Myanmar seems to have come from Senior General U Than Shwe, Head of State from 1992 to 2011. In his final months, the military government decreed two laws to establish SEZ's, which were later replaced by the SEZ Law 2014 (International Commission of Jurists, 2017). The SEZ's attract investments, which make these locations suitable for deep sea port development. Therefore it can be relevant to investigate the considerations for selection of the SEZ sites at Thilawa, Kyaukpyu and Dawei, depicted in Figure 21.

The SEZ's in Myanmar are governed by the Special Economic law, which was decreed by the military junta in January 2011 and has been upheld by the current government which is still influenced by the military. In order to enhance the port development project at Dawei, the previous military government enacted the Dawei Special Economic Zone Law on January 27, 2011 (Min, Aung, & Kudo, 2012). The current SEZ's, determined by the military regime, cannot be withdrawn. However, section 12 of Chapter VI ''The establishment of Special Economic Zone'' states that ''The Central Body may establish the Special Economic Zone by the approval of Pyidaungsu Hluttaw with the agreement of the Union Government in the suitable place or area for development of State economy based on the following criteria, the location should:

a. Have international gateways such as ports and airports, or can transport easily to international border or domestic markets
b. Be the area designated for regional development by the Union Government
c. Have the infrastructural pre-requisites or having the prospect for the implementation
d. Have the availability of water resources and electric power
e. Have sufficient land area to establish the industries and the investment business
f. Have skilled workers, semi-skilled workers and trainable workers
g. Be able to arrange training courses for the recruitment of required skilled workers
h. Be the strategic area or land in the condition of transportation or linkage to the market in the country

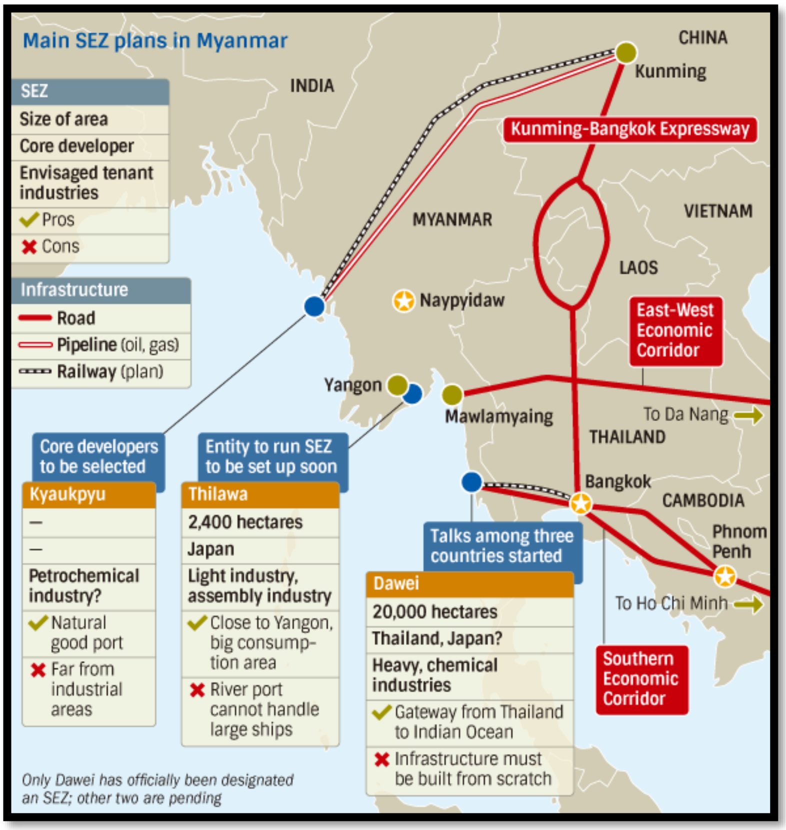


Figure 21: SEZ locations and status in 2013 (Nikkei Asian Review, 2013)

These criteria are in fact site selection criteria, and most of them will be used for the framework and site selection process in this research. The criteria as stated above in the enumeration are formulated to concise, and are not suitable for direct use. Therefore they are adapted, and described in more detail for use in the MCA in section 6.3.

SEZ's are regulated by the SEZ Law 2014, and governed by national level SEZ management committees. In 2017, the International Commission of Jurists assessed whether the legal framework governing SEZ's is in conformity with the States duty to protect human rights. The recent development of SEZ's in Myanmar has been accompanied by documented human rights violations and abuses. These abuses involve violations of internationally recognized rights to food, health and adequate housing, as well as procedural rights to participate in development (International Commission of Jurists, 2017). This should be investigated in more detail.

4.4.4 Site selection study by Myanmar Maritime University

This chapter with findings and insights from the case study concludes with findings from a recent (May 2018) site selection study by the Myanmar Maritime University (Velkavrh & Naing, 2018). Their proposed deep sea port site is near the city of Pathein (Nga Yoke Kaung) in the Ayeyarwady region, as can be seen in Figure 22.

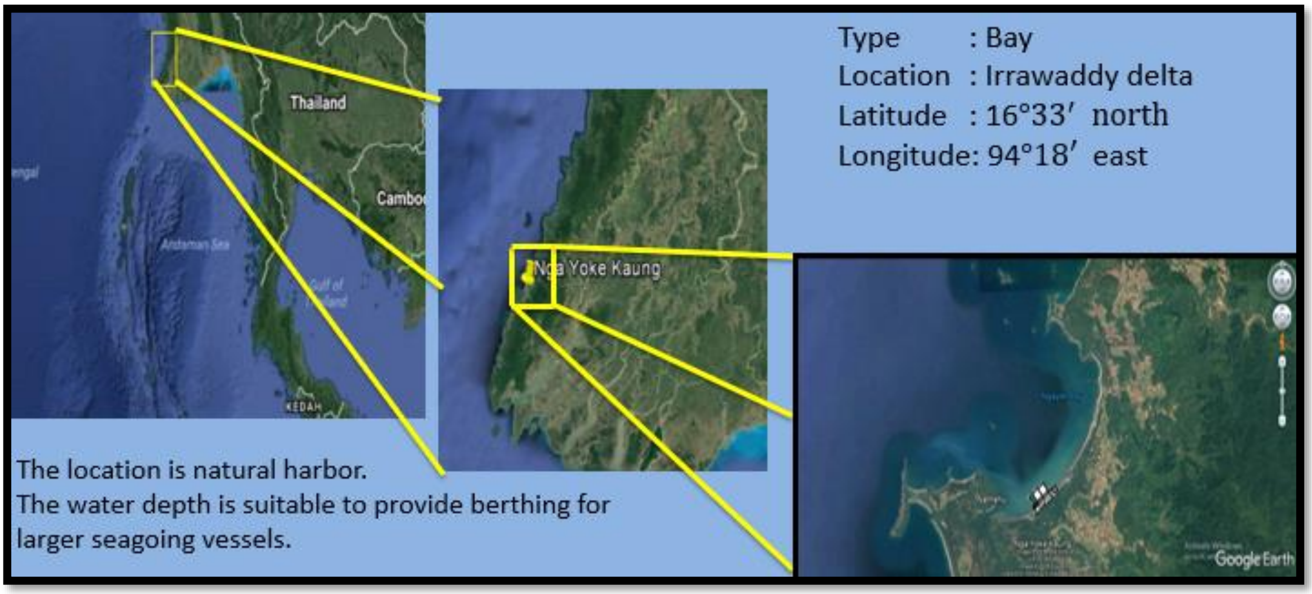


Figure 22: Deep sea port site at Nga Yoke Kaung (Velkavrh & Naing, 2018)

Velkavrh & Naing provide the following motivation for this deep sea port site:

- The location is a natural harbor which provides shelter against waves and currents.
- The water depth is suitable for berthing larger seagoing vessels (10 m near shore).
- The location is a good access to India, Africa, Europe, Middle-East and Western countries (however this can be said for every port location in Myanmar).
- The port will serve as a transshipment zone between Western and Eastern parts of the world.
- The port is located near the East West corridor and from there a direct access to Pathein is available (this is doubted by the author because the East West corridor is almost 600 km to the East).
- No hard rock or extremely soft soils.
- Located near the city of Pathein (350.000 inhabitants) with basic industry, universities and some tourism.
- 50 MW power plant will provide power for local population and industry.

Figure 23 shows several traveling distances. From Nga Yoke Kaung to the closest city port of Pathein, the sailing distance is 225 km. Towards Yangon it is 430 km, and from Nga Yoke Kaung by road towards the large hinterland of the Greater Mekong Sub-region, 730 km has to be travelled. These are all relatively long distances, which probably increase logistics costs from a potential deep sea port at Nga Yoke Kaung.

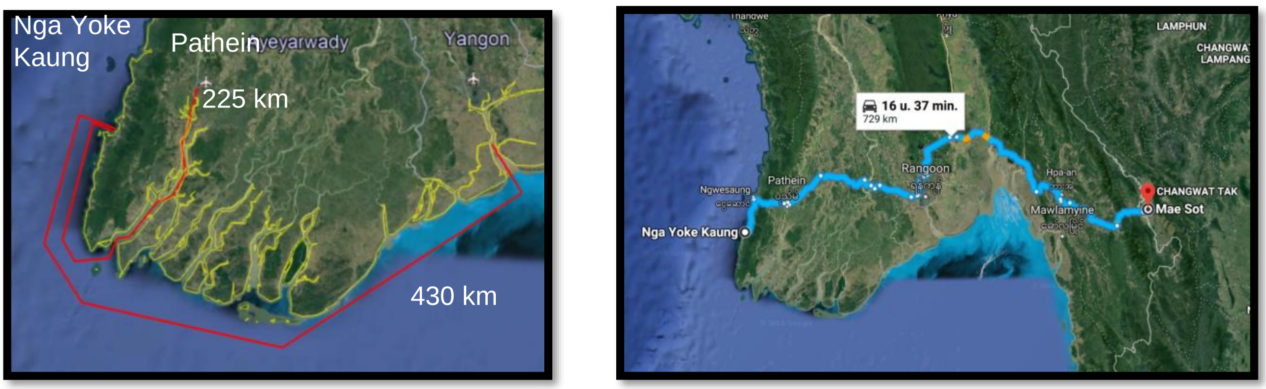


Figure 23: Distances to Pathein, Yangon, and the Greater Mekong Sub-region

5 FRAMEWORK DEVELOPMENT

The initial framework as presented in section 2.4, is improved in a bottom-up approach based on a case study in Myanmar, using a stakeholder-inclusive approach including literature study, and views and insights obtained from meetings with stakeholders and a final workshop. The framework can be seen as a gathering of insights from the case-study and presents all aspects which should be taken into account during the site selection process in Myanmar in a schematic, stepwise way. First, the proposed framework (Figure 24) is presented and subsequently the motivation for the framework is discussed. The framework is validated in section 5.5 and section 5.6 presents the final framework after refinement which will be applied in chapter 6.

5.1 Proposed framework

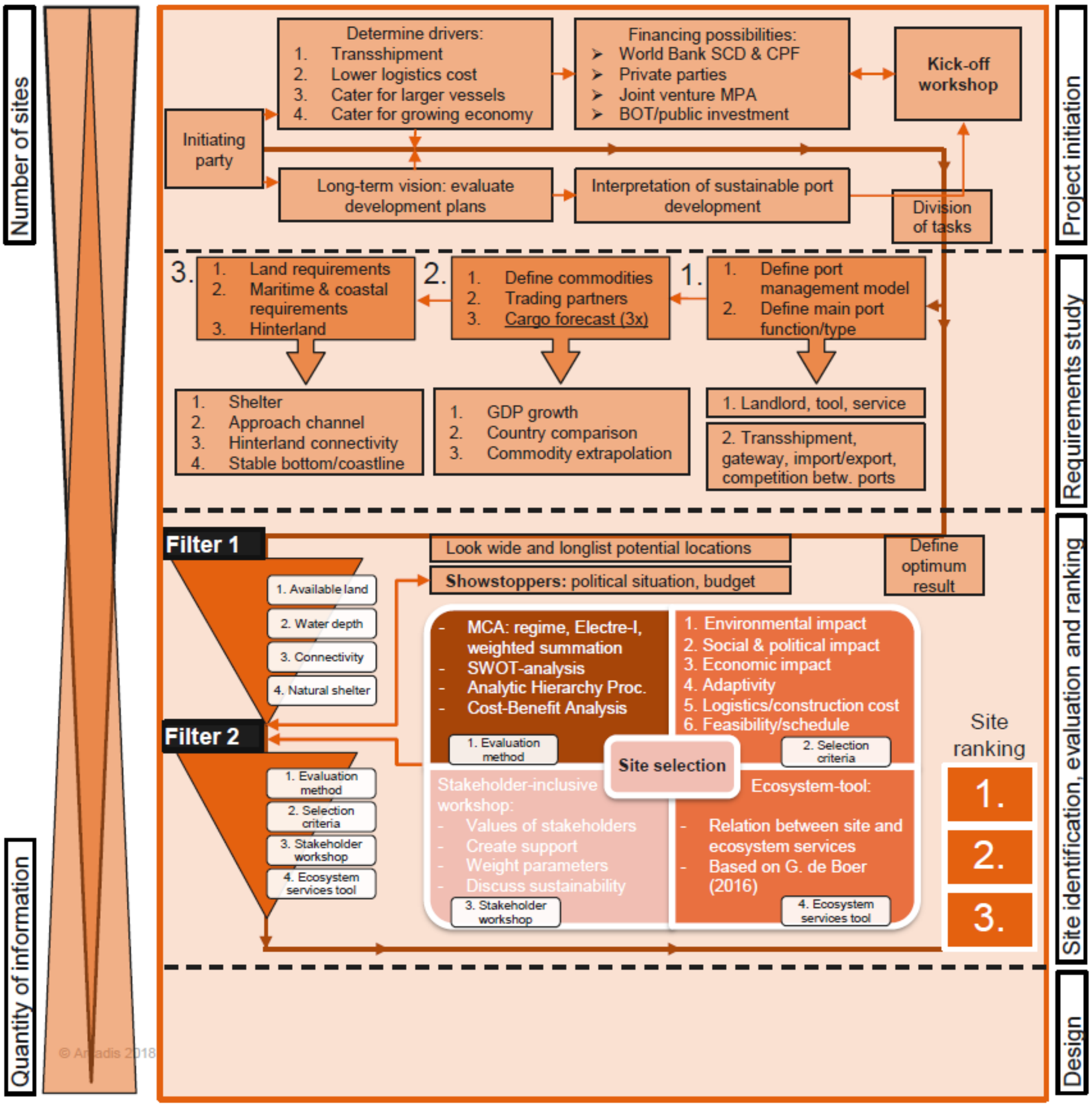


Figure 24: Proposed site selection framework (source: author)

Important to mention is the division in four phases: project initiation, requirements study, site identification, evaluation and ranking, and the design phase. In port engineering, it is common that the first two stages are already carried out when the process of site selection starts. In this research, during the Myanmar case-study, these two stages were not carried out and are therefore included in the framework only for clarity. However, the core of this research concerns phase 3 'Site identification, evaluation, and ranking' and phase 4 'Design'. Phase 1 and 2 are discussed in chapter 3.

5.2 Key findings: stakeholder consultation

Stakeholders can have large influence on the framework, as they reflect the country's needs, problems, and priorities regarding deep sea port development and site selection. As little is written in national development policies, stakeholder values and insights are of great importance. This section elaborates upon the most valuable stakeholder insights from the consultations. The following topics related to framework development are used during the interviews:

- Criteria/considerations for current and past site selection and port developments in Myanmar
- Views of stakeholders on the needs for deep sea ports in Myanmar
- Overview of port development and site selection policy in Myanmar
- Selection parameters and their importance for selection of deep sea port sites

In this section, four interviews are discussed. In total, twenty stakeholder consultations are carried out. A complete overview of the interviewees can be found in Appendix C. Interviews 16 – 20 are used for validation of the framework. Interviews 3, 4, 7 and 10 are described separately because these interviews delivered the most valuable insights into ports in Myanmar. The remaining interviews are used incidentally throughout chapters 5 and 6.

Interviewee 3 (27-10-2017) - The chairman of the Myanmar Engineering Council, former rector of Myanmar Maritime University, and author of 'Port and Shipbuilding in Myanmar' (2013):

A good deep sea port location is as close to Yangon as possible, because all hinterland connections in Myanmar are in some way connected to Yangon. The minimum investment in infrastructure should be done. According to interviewee 3, no one in Myanmar knows which location is best, because all deep sea port projects are introduced, owned and executed by foreign parties. These foreign parties try to tell Myanmar which location is the best one, however Myanmar needs its own site selection policy. Interviewee 3 mentions water depth and the accompanying size of vessels as the most important criteria for site selection in Myanmar. The development should aim for serving Post-Panamax vessels.

Interviewee 4 (31-10-2017) - The Chief Financial Officer of Myanmar Industrial Port:

Similar to interviewee 3, interviewee 4 thinks a deep sea port should be as close to Yangon as possible and a large piece of land for back-up is required. A location close to the inner city industrial hubs is important, otherwise no one is going to use your port. Site selection policy in Myanmar is unclear, however connection with Yangon is by far the most important criterion for deep sea port site selection. Thilawa Port (16 km downstream from Yangon) still receives low volumes of cargo because there is no connection: *''It doesn't matter how good you are in port operating, if you are not connected to where the box needs to be, you are not connected hardly at all.''* After proximity to Yangon, water depths and the dredging volume are most important.

A major problem in deep sea port development is financing. What often happens: a plan arises, free-grant money is earned from NGO's to study feasibility with consulting firms, a plan is developed, and the financing problem begins. Before development of new ports, questions are raised: is it really needed? Compare Myanmar's situation with Vietnam's situation 10 or 20 years ago, when did they change from inner city ports towards deep sea ports? And Thailand?

Another problem is the large amount of empty containers at the ports. 100% of the containers that come into Myanmar, are loaded. 75% of the boxes that leave, are empties. The 25% which leave and are loaded have rice and pulses in it. There is no value-addition, and export is only rice, beans, jade, timber, natural gas, fuel. Storage of empties only costs $2 per day, which causes congestion in the ports.

Interviewee 7 (10-11-2017) – Chief Executive Summary Kanaung Legacy Limited:

In agreement with interviewee 4, interviewee 7 states that financing of developments is the biggest challenge. Japan, Korea, and China grant the project or provide a soft loan, so they provide a full package for port development. So financing is a problem, especially if the World Bank is not going to finance it. Interviewee 7 does not think foreign companies will invest in Kyaukpyu or Dawei as everybody thinks the economic heart is and will remain in Yangon. Another challenge in Myanmar, also stated by interviewee 4, is the large number of empty containers. The current situation is characterized by import strongly exceeding export.

According to interviewee 7, distance and connection to the industry zones (without traffic jams) is the most important selection criterion. Next to connectivity, well-trained staff is required and also a big problem in Myanmar. Interviewee 7 agrees with interviewee 4 that deep sea port development should start with the support of the big terminal operators. Provide them with a full plan, including financing and their share, and if the terminal operators don't join, they are out of business.

Interviewee 10 (17-11-2017) – Head of Transportation Arcadis Asia:

Mr. Jonathan Beard states deep sea port development is about economies of scale, and recommends support and encouragement from the terminal operators, instead of (mostly Japanese and Chinese) contractors, as port proposals in Asia are often driven by Chinese interest. Focus of Myanmar's deep sea port development should be on supporting their import and export, and there is no need for transshipment on the short term. Ocean transshipment has a lower yield (60% of the revenues for an import/export lift), and the major hubs are Port of Singapore, Tanjung Pelepas and Port Klang. It is hard to compete with these 3 and Myanmar needs at least 4 mln TEU before competing as transshipment hub.

Concerning site selection, there are limited suitable places for deep sea port development, and the best water access is the worst land access. Road and river transport should be considered as most important transportation methods, and sites should be big enough for at least 40 years because 10 mln TEU's in 40 years is a reasonable estimate. When executing the trade-off between locations, make sure stakeholders understand the trade-off to create support.

Stakeholders views on best location and site selection criteria

Not all stakeholders had knowledge about Myanmar's site selection methodology, however most of them gave good insights into important site selection criteria and the best site according to their opinion. These results are presented in Table 28.

Table 28: Results from stakeholder consultations on site selection criteria and optimum port sites

Criterion	Nr.	Interviewee		Site	Nr.	Interviewee
1. Hinterland connectivity	7 x	1, 3, 4, 5, 7, 12, 14		1. Yangon	4 x	1, 3, 4, 5
2. Proximity to Yangon	5 x	1, 3, 4, 7, 12		2. Dawei	3 x	1, 2, 12
3. Financing plan	3 x	4, 7, 14		3. Pathein	2 x	1, 5
4. Workforce	2 x	7, 14		4. Mawlamyine	1 x	1
5. Water depth	2 x	3, 12		5. Myeik	1 x	7
6. Available back-up land	1 x	4		---	---	---
7. Fast development	1 x	3		---	---	---

The column 'criterion' shows seven site selection criteria mentioned during the stakeholder consultations. The column 'Site' shows five port sites mentioned during the stakeholder consultations. The column 'Nr.' shows the number of times that the specific criterion or site is mentioned during all stakeholder consultations. The column 'Interviewee' shows the specific stakeholders which mentioned the specific criterion or site during the stakeholder consultations. An overview of these stakeholders and all interviews can be found in Appendix C.

According to the stakeholders in the multi-stakeholder workshop (section 5.4.3 and Appendix I), the biggest challenge with respect to port development in Myanmar is the limited budgets and search for investors. Besides, a lack of up-to-date infrastructure in combination with new and frequently changing port development policies are mentioned as challenges in the nearby future.

The stakeholder consultations gave clear insights about priorities related to port development. Besides, in individual consultations stakeholders spoke about problems, challenges and disagreements concerning port policy. Data from these stakeholder consultations will be used for setting up the site selection criteria in section 5.4.2, and data regarding preferred sites will be used as input for the site recommendation in section 6.3.5.

5.3 Key findings: literature, desk & case study

During the case study and enhancement of the initial framework, lack of knowledge about several subjects came forward. For example a lack of knowledge about different evaluation methods. Insights from literature and desk study which will be used for framework enhancement, are presented in this section.

5.3.1 Decisions on a finite set of alternatives (DEFINITE)

A decision support system to structure a decision problem is ''decisions on a finite set of alternatives'' (DEFINITE, Dutch acronyme BOSDA). DEFINITE is a decision support software package that has been developed to improve the quality of environmental decision making. DEFINITE can weigh up alternatives and assess the most reasonable alternative (Janssen & van Herwijnen, 2007). DEFINITE comprises of the below mentioned steps, which will be used in the site selection framework:

1. **Problem definition:** during the 'definition phase', a problem is given concrete form. The first task is to identify the objectives (e.g. minimize costs, minimize environmental impact) and how these objectives can be measured. This is done using criteria, each of which will be allocated a certain score during the analysis.
2. **Standardization:** before applying a multi-criteria method in most cases it is necessary to standardize the criteria table. This is because incompatible measurement units (euros and kilometers) need to be reflected.
3. **Classification:** after completing standardization, some insights can be gained into the strengths and weaknesses of the different alternatives. However, criteria weights are needed for the final classification.
4. **Weighting:** in order to apply a MCA method, all criteria have to be allocated a certain weight. The weight factors serve to compare whatever values might occur between the minimum and maximum of the criteria scores. It is possible to distill weights by means of interviews, inquiries, and analysis of past decisions. Commonly used methods are:
    1. **Pairwise comparison:** with pairwise comparison of each pair of criteria the most important criteria must be chosen and to which degree (slightly more important, much more important, etc.). On the basis of these results, quantitative weights can be calculated.
    2. **The expected value method:** with this method the researcher himself should arrange the criteria in a consistent order. If criteria are of equal importance, they can be located at the same position in ranking. The more important the criteria become, the bigger the differences between weights.
    3. **The random weight method**: does not produce separate weights, but must be used in combination with certain MCA methods, resulting in a certain ranking of the alternatives.
    4. **The extreme weight method**: does not produce separate weights, but must be used in combination with certain MCA methods, resulting in a certain ranking of the alternatives.
5. **Selection of MCA method:** various methods for putting alternatives in order exist, which do not always lead to the same result. Selection of the method depends on the quantitative or qualitative nature of the scores and the weights. In principle, each criterion to order policy alternatives can be measured qualitatively or quantitatively. Some MCA methods are designed to process only qualitative information, such as the weighted summation method. In practice, this disadvantage is not very significant because the pluses and minuses used for qualitative assessments are often derived from underlying classes of quantitative data. With a well−chosen method of standardization such as goal standardization this underlying quantitative scale can be used in the weighted summation of these scores (van Herwijnen, Multi-Criteria Analysis Tools, n.d.). DEFINITE distinguishes between four MCA methods:
    1. **Weighted summation:** with this method the standardized effect scores are multiplied by the matching criteria weights and then summed for each alternative in turn.
    2. **The Electre method:** this method is also called *concordance* analysis and uses quantitative weights and scores. This method is an ongoing pairwise comparison of scores per criteria.
    3. **The Regime method:** the regime method makes use of pairwise comparison and is well suited for working with qualitative scores and weights. This method uses the random weight method or the pairwise comparison for determination of weight factors.
    4. **The Evamix method:** this method involves dealing with qualitative and quantitative scores separately. Dominance tables for both scores are made, similar to the matrices in the concordance analysis. This method is less transparent and less efficient.
6. **Sensitivity:** after a ranking of alternatives, an important step is testing whether the order of alternatives changes if slight variations occur in the output values. The purpose of a sensitivity analysis is to determine the degree of variation there has to be in the original data and weighting to cause a change in ranking.

5.3.2 PIANC Working group 185

PIANC Working Group 185 works on guidelines for site selection and development of greenfield port developments. It is an extension of PIANC Working Group 158 ''Guidelines for brownfield port developments''. A greenfield site is defined by PIANC as: ''*a site which has not been previously used as a port/terminal and is not constrained by previous use. It is usually undeveloped but could equally be a 'brownfield' site whereby it has been developed for other uses in the past''.*

During framework development, the first results of the PIANC Working Group 185 became available (PIANC, 2018) which will be summarized in this section. These first PIANC results can also be used to compare with the initial framework in section 2.4. The site selection process as constructed by PIANC 185 comprises of six steps, as presented in Figure 25. The full process and an elaboration of each step can be found in Appendix F. This section will discuss aspects of the PIANC site selection process which are similar to the initial site selection framework in section 2.4, or valuable aspects which can be adapted and used for development of the site selection framework in this research. There are several similarities between the initial framework in section 2.4 and the PIANC site selection process in Figure 25 and Appendix F.

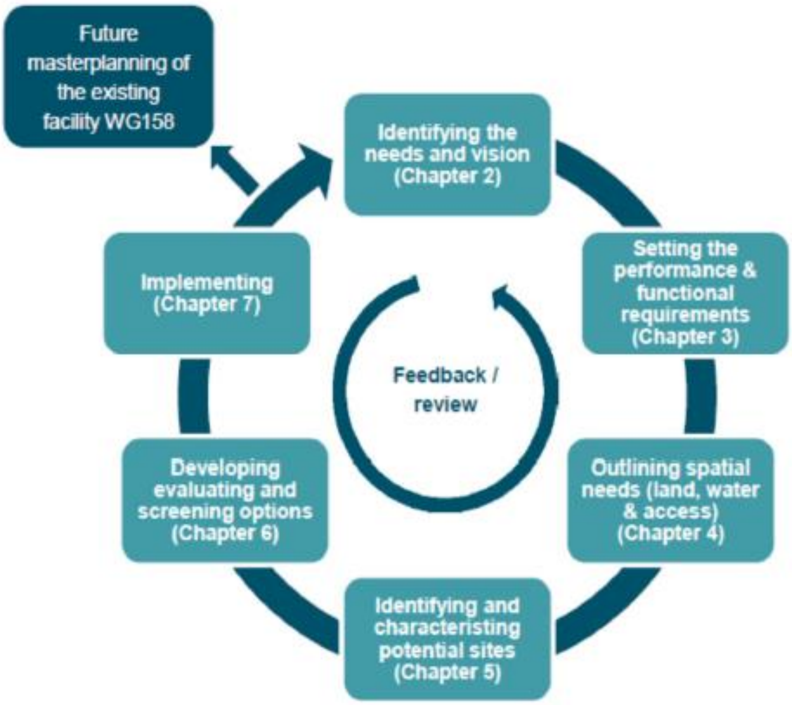


Figure 25: Site selection in six steps (De Jong, 2018)

- The steps in the PIANC process can be compared with the research steps followed in this report which first identifies the needs and values for the port, subsequently determines spatial needs and identifies possible sites, and lastly investigates different evaluation methods for site selection.

- The site selection process can roughly be divided in 2 phases. In this research a division is made between a 'long list' of possible sites and a 'short list' of possible sites. The long list is determined based on four 'must-have criteria', after which the short list is evaluated based on six weighted selection criteria. The 2 phases of the PIANC site selection process are named 'gate 1' which is evaluation based on mandatory criteria (must-haves), and 'gate 2' which encompasses evaluation based on supplementary criteria (wants). After the two gates a choice should be made for the type of evaluation method. This process based on 2 gates is shown in Figure 26 on the next page.

- Another similarity concerns the evaluation methods for ranking the potential sites. The initial site selection framework in section 2.4 included a Multi-Criteria Analysis, and the Analytic Hierarchy Process which uses the pairwise comparison. The earlier mentioned DEFINITE decision support system also uses various types of Multi-Criteria Analysis and the pairwise comparison for weighting of selection criteria, which implies these are very suitable methods for site selection. PIANC suggests the methods presented in Table 29.

- Lastly, feedback/review/iteration is suggested in both frameworks.

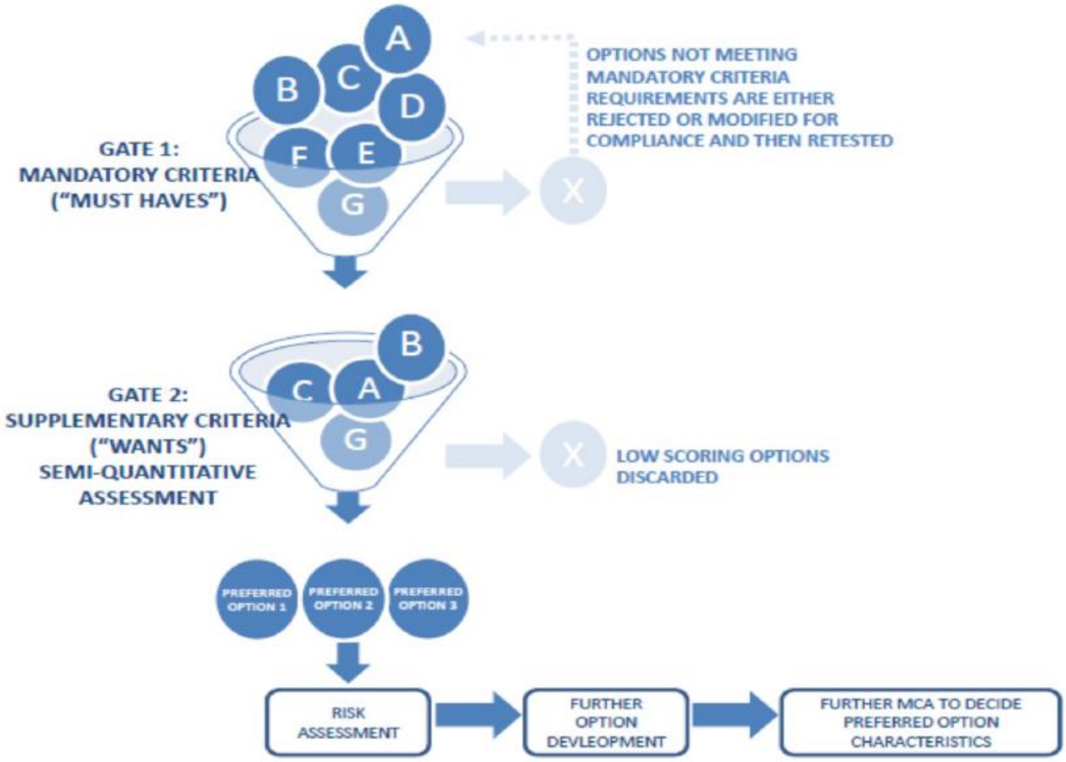


Figure 26: 2-step evaluation process (PIANC, 2018)

The evaluation methods from PIANC mentioned in Table 29 show large similarities with the selection methods as stated by Glatte (2015) in Figure 4. Glatte (2015) mentions the pairwise comparison, preference matrix (multi-criteria analysis), and the SWOT-analysis in location selection strategy which indicates that these methods are very well suitable for site selection. Based on the occurrence of multi-criteria analysis in every site selection reference, it can be concluded this is one of the most common evaluation methods. Motivation for selection of the evaluation method in this research is presented in section 5.4.1.

Table 29: Site evaluation methods (PIANC, 2018)

Evaluation method	**Description**
Benchmarking	Needs information on relevant similar ports.
SWOT-analysis	Effective at improving options by addressing SWOT (strengths, weaknesses, opportunities and threats) but does not provide a clear comparative measure between options.
Subjective screening	Requires expert opinion across all relevant technical aspects, and thus easily challenged. Very efficient at refining a long list with options but all major alternatives should be retained for the more rigorous phase of selection.
Pairwise comparison	Two options are compared on subjective assessment merits. The preferred option is then compared with the remaining option. This method relies on expert opinion, and is especially effective at reaching agreement on one option from a small disparate set of options. If criteria can be scored then MCA is more robust.
Multi-criteria analysis	Criteria are scored and a weighted sum is derived which ranks the options. Can be extended to include wider range of opinions for both the weighting and scoring. Sensitivity testing is possible. Relevance of criteria can be tested by the ability to differentiate between options refined.
Economic appraisal	Monetary value is assigned to all effects of the schematization. Requires definition of income and expenditure over time, a definition of a reference period and interest rate, and evaluation of social, environmental and safety criteria in monetary values.

The four beforementioned similarities ‘structure of process’, ‘2-step evaluation process’, ‘iteration’ and the ‘evaluation methods’ will be included in the site selection framework. Besides these similarities, also some suggestions to the PIANC process are made:

- Planning of financing and acquisition is advised in step 6 of the site selection process by PIANC. Based on the stakeholder consultations, planning of financing should be arranged as early as possible, before the technical site selection aspects.
- It is not clear whether the filter process in the PIANC methodology is ‘situation-specific’. It is recommended to use the filter process situation-specific because every country and every site selection process has different drivers and objectives which should be used as input for the filters.
- For site selection in developing countries, it is advised to include financing procedures and criteria from development banks in the process.
- The choice between a gateway (import/export) or transshipment port (or a combination of these types) is of vital importance for site selection of deep sea ports.

It is important to mention that the PIANC reference in this section originates from an intermediate PIANC presentation where first results of the Working Group 185 were presented. It is expected that the work of PIANC has been further developed in the meantime, and the abovementioned should been as suggestions.

5.4 Framework phase 3: site identification, evaluation and ranking

As mentioned in the introduction of this chapter, the core of this research and the framework contains site identification, evaluation and ranking, in accordance with the third stage in the framework (Figure 27). The following four sections elaborate on the different motives for constructing the framework, but also on motives for alternative use of the framework, e.g. different evaluation methods. The basic idea of phase 3 is a 2-step process in which sites are identified based on the four key considerations available land, water depth, connectivity, and natural shelter. After this first filter, filter 2 is proposed based on six selection criteria evaluated in a MCA. The results of this MCA can be found in section 6.3.3.

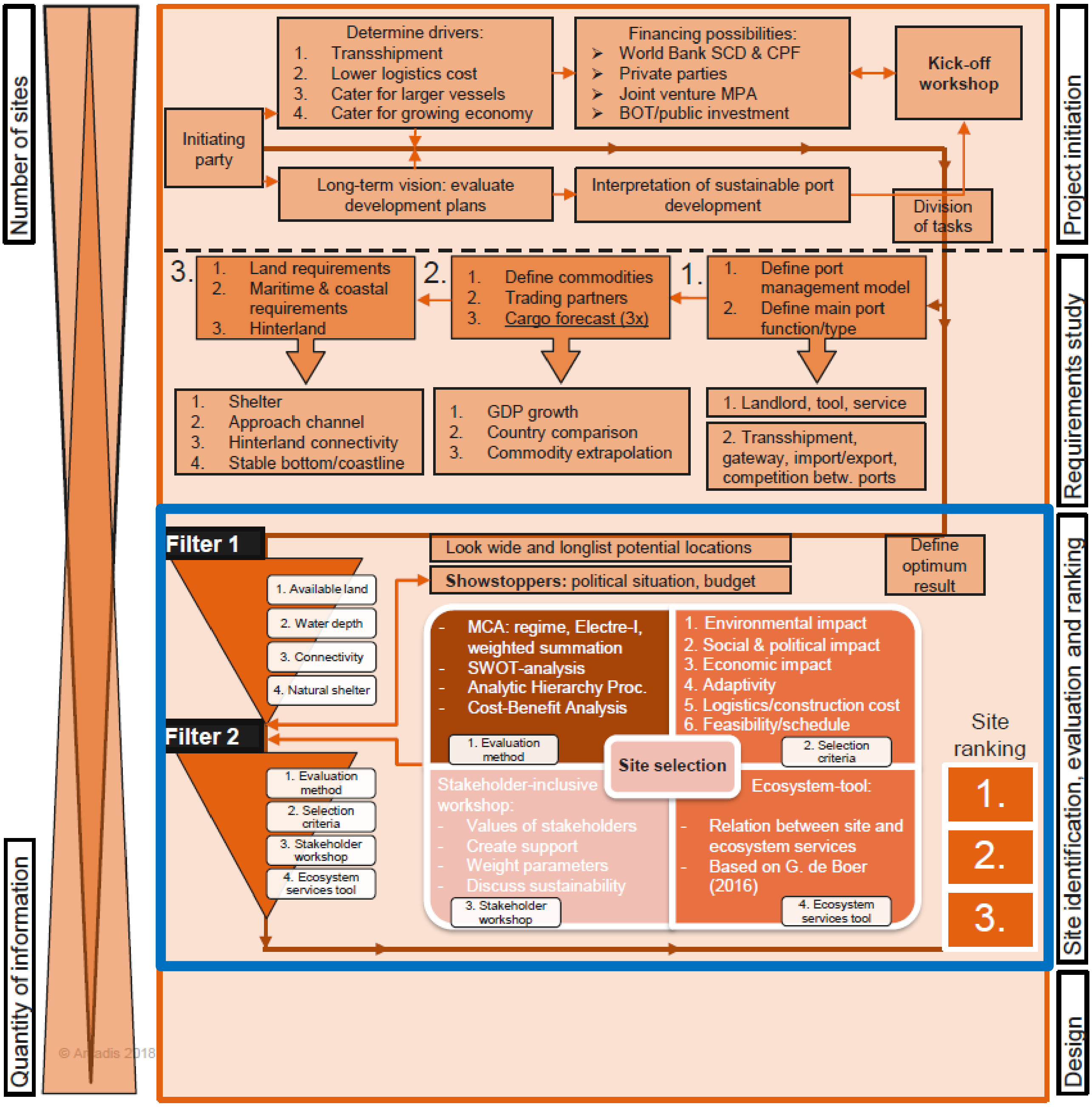


Figure 27: Stage 3 of the framework, denoted by the blue rectangle (source: author)

In the following sections, first a trade-off between several evaluation methods is described, with a focus on different types of MCA's. After selecting the evaluation method, criteria for selecting a specific site are presented. The subsequent sections elaborate on a multi-stakeholder workshop including weight parameter determination, and the application of the concept of ecosystem services in the second filter. Lastly, alternatives for the 2-step process are given. For example, it is possible to use the first filter as a 'sustainability filter', if policy is aimed strongly towards sustainable options.

5.4.1 *Selecting the evaluation method: MCA/MAMCA*

Many different evaluation methods exist for decision problems like the problem addressed in this research. A decision-support specialist from Arcadis mentioned that the state-of-the-art decision technique is Cost-Benefit analysis (economic appraisal), which is the most common technique used nowadays. Complex and unstructured decision problems, involving a number of conflicting and a variety of stakeholders call for proper evaluation tools. MCA serves as a useful tool as it is able to: capture plurality of dimensions involved in planning problems, prioritize alternative solutions, support decision making in a transparent and coherent way, increase participatory potential by involving priorities of a broad range of stakeholders, and it offers a platform for structured debate with stakeholders (Stratigea & Grammatikogiannis, 2012). Key advantages of MCA's relate to its possibilities to (Finco & Nijkamp, 1997 in Stratigea & Grammatikogiannis, 2012):

- Take into account a diverse set of criteria that are important for the evaluation problem
- Take into account both quantitative and qualitative aspects
- Establish a structured communication method with decision-makers and policy-making bodies through the use of a range of policy weights for respective evaluation criteria
- Address future uncertainties by including scenario experiments in the analysis

Many different MCA techniques exist, and selecting the right one should consider questions relating to the nature of the data handled (quantitative, qualitative, mixed), the relationship between policy objectives and selection criteria, the nature of the attached weight parameters (qualitative or quantitative), the treatment of outcomes of alternatives in the effect matrix, the type of standardization used, etc. Use of different methods can sometimes lead to divergent results, and it is therefore suggested by many authors to use two or more MCA methods in a certain evaluation problem in order to validate the obtained results. Several decision trees have been developed for selecting an evaluation method, for example the decision tree in Figure 28 by Vreeker et al. (2001), which assists in choosing between a Cost-Benefit analysis, Regime MCA analysis, Saaty's Hierarchical method, and the flag model.

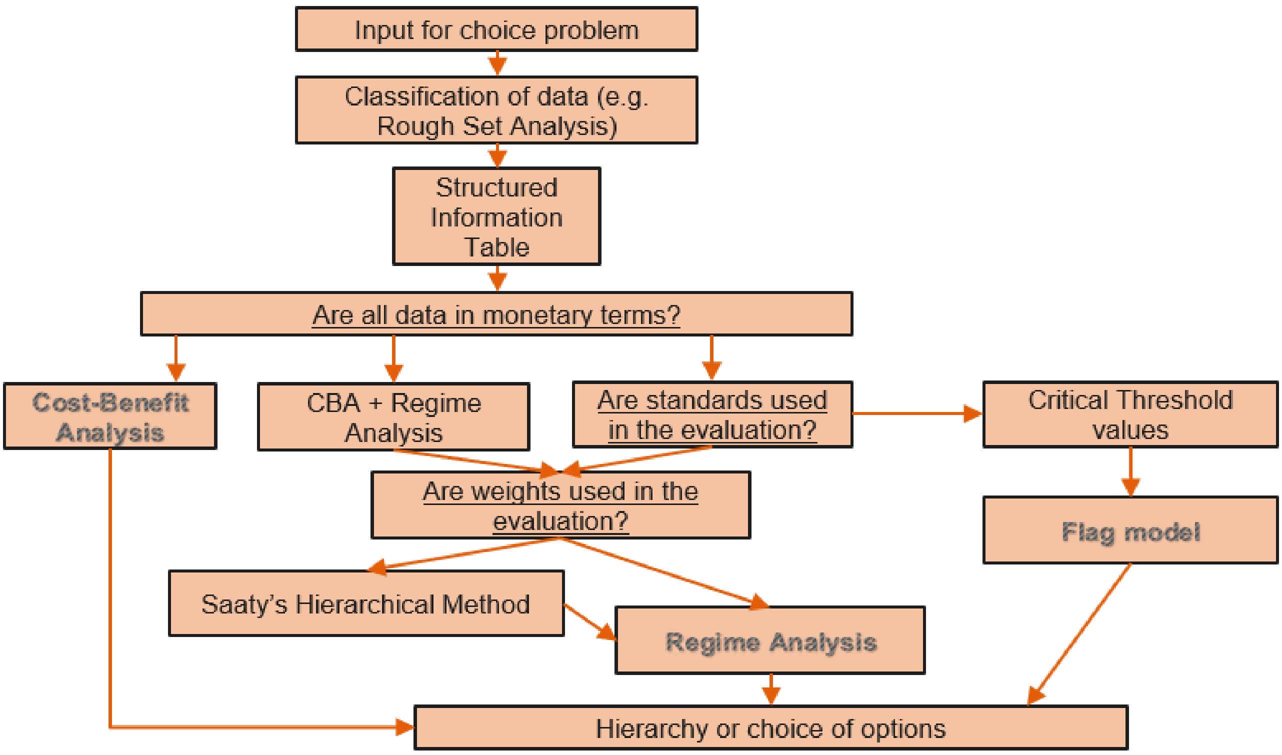


Figure 28: Decision tree for selecting evaluation methods (Vreeker et al. 2001)

In this research, qualitative and quantitative (mostly qualitative) data is used as input for the selection criteria which will be motivated later on, and no monetary values are present. Standards are not used, and weights are determined by using a pairwise comparison. Following the decision tree, regime analysis is most suitable. An important motivation for choosing REGIME-analysis (or another type of MCA) is the ability to handle both qualitative and quantitative data. In practice, every method is capable of handling qualitative data because qualitative data can be converted into quantitative data by means of standardization, but caution is advised.

Another reference which assists in choosing between the two most common methods for project evaluation CBA and MCA, is provided by van Wee et al. (2013) presented in Figure 29.

	Social Cost-Benefit Analysis	**Multi-Criteria Analysis**
Systematic comparison of alternatives	Yes	Yes
Explicit formulation of weights in trade-offs	Yes	Yes
Basis for weights of various effects	Valuation by consumer	Political valuation
Opportunities for abuse by policy makers	By manipulation of inputs	By manipulation of inputs and by manipulation of weights
Degree of compensation between various attributes of alternatives	Every unfavorable attribute can in principle be compensated by a favorable outcome for another attribute	Various degrees of compensation are possible through the possibility of incorporating minimum requirements
Risk of double counting	Limited	Yes
Opportunities to take into account attributes that cannot be valued in monetary terms	No	Yes
Possibility of attaching weights to the interests of specific actors	Not in the standard form of SCBA	yes

Figure 29: Comparison SCBA and MCA (Van Wee et al. 2013)

Based on the three highlighted considerations in Figure 29, and the beforementioned considerations from Figure 28, the Multi-Criteria Analysis will be used in the site selection framework for this research:

1. The weights in this research are valued by mixed stakeholders, however mostly by politics. Consumers or 'users' of the future ports are terminal and port operators, and shipping lines, which were not willing to participate in the workshop carried out for this research (section 6.3.1). Moreover, the concerned governmental organizations eventually decide on site selection of ports.
2. Social Cost-Benefit Analysis (SCBA) does not provide opportunities for taking into account attributes that cannot be valued in monetary terms. During the case study and setting up the selection criteria, it became clear that little monetary information is available, and that setting up a Cost-Benefit Analysis would take too much time.
3. In MCA's, it is possible to attach weights to the interests of specific actors, which makes it possible to formulate different scenario's, based on different actor interests. This is especially relevant in a country like Myanmar with a new government and changing interests.

Now the evaluation method, the multi-criteria analysis, for the site selection process in this research has been chosen, it is necessary to elaborate on this method in more detail. In MCA's, policy alternatives are evaluated according to the effects of a number of criteria, which are often clustered such as effects on safety, effects on environment, effects on construction costs and so on. The effects of different alternatives are represented in an evaluation table. A second aspect of MCA's is the indication of the importance of the criteria by assigning weights determined by policy makers or determined by the researcher based on decisions from the past. By applying the weights on the different criteria, a ranking of policy alternatives is obtained (van Wee, Annema, & Banister, 2013). A wide variety of methods exists to arrive at these rankings. As mentioned on the previous page, the regime method is one of the possible MCA alternatives. In order to provide an indication of the list of different MCA's, and to provide a basis for choosing the right methods, Appendix G and Appendix H provide an overview with 29 descriptions and comparisons of MCA methods (Guitouni & Jean-Marc, 1997). In the more recent article ''Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment'', by Cinelli, Coles & Kirwan (2014), it is argued that researchers usually do not properly define the reasons for choosing a certain MCA instead of another. Familiarity and affinity with a certain method seem to be the main drivers for selecting a method. Cinelli et al. present the performance of five methods in respect to ten crucial criteria that sustainability assessments should satisfy, among which are a life cycle perspective, thresholds and uncertainty management, software support and ease of use, presented in Figure 30. All considered methods can handle information that is qualitative and quantitative in nature, with the qualitative being reduced to point scales.

Multi-Actor Multi-Criteria Analysis (MAMCA)

In addition to the classic MCA denoted in Figure 29, Hadavi et al. (2018) propose the MAMCA, which makes the different stakeholders explicit in the appraisal methodology. MAMCA is a methodology to evaluate transport projects, and aid groups in decision-making. In order to include the stakeholders' opinions into the decision-making process, during the problem formulation phase, the stakeholders are identified together with the possible alternatives. Thereafter, the stakeholders' criteria and priorities will be gathered. Finally, the alternatives will be evaluated on the gathered criteria. Hence, the MAMCA approach adds an extra 'actor layer' to the traditional MCA methods and is in fact application of a MCA for every actor, which is described in more detail in section 6.3.5. The following steps can be identified in the MAMCA-approach (Macharis et al. 2008):

1. **Define alternatives**: identifying and classifying the possible alternatives for evaluation.
2. **Stakeholder analysis**: the stakeholders are identified in the stakeholder analysis. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders which need to be consulted.
3. **Define criteria and weights**: in the MAMCA methodology, the criteria for the evaluation are the goals and objectives of the stakeholders, and not the effects or impacts of the actions per se as is usually done in a Multi-Criteria Analysis. In a natural way, these impacts will be reflected in the goals of the stakeholders if all relevant stakeholders are included. The weights are then determined by the importance the stakeholders is attaching to each of his or her objectives.
4. **Criteria, indicators and measurement methods**: at this stage, similar to the MCA-approach, the evaluation criteria are being operationalized by constructing indicators that can be used to measure to what extent an alternative contributes to each individual criterion.
5. **Overall analysis and ranking**: any MCA-method can be used in the MAMCA-approach to assess the different strategic alternatives. The most suitable methods are the group decision support methods (GDSM) which are able to cope with the stakeholder concept, and allow each stakeholder group for having their own criteria, weights and preference structure, and only at the end of the analysis the different points of view are being confronted.
6. **Results**: The used MCA method leads to a ranking of alternatives. A sensitivity analysis is performed in order to see if the result changes when the weights are modified. The MAMCA-approach provides a comparison of different strategic alternatives, and supports the decision-maker in making his final decision by point out for each stakeholder which elements have a clearly positive or a clearly negative impact on the sustainability of the considered alternatives.
7. **Implementation**: after decision-making, steps have to be taken to implement the chosen alternative by creating deployment schemes. The information on the points of view of each stakeholder, received from the previous steps, tremendously helps to define the implementation paths.

Steps 1, 2, 4, 6 and 7 are almost similar to the steps in a classic MCA-approach. Steps 3 and 5 are significantly different from the MCA-approach. In step 3 in a MCA-approach, the evaluation criteria are the effects or impacts of the actions while in a MAMCA-approach, the evaluation criteria are the goals and objectives of the individual stakeholders. In step 5 in the MCA-approach, an evaluation method is chosen and described once with the combined weight parameters from all stakeholders, whereas in the MAMCA-approach an evaluation method is used which allows for having individual criteria and weights for every stakeholder. Subsequently, the chosen evaluation method is carried out for every stakeholder.

During the research process, use of a Balanced Scorecard (BSC) as evaluation method came forward. The BSC is a method for measuring business performance including a mechanism to provide a direct relationship between performance indicators and strategy, a simplified set of indicators with a framework help in strategic planning and management, and a focus to measure strategic performance driven by mission and vision (Rahman & Chin, 2013). In 2013, the BSC was not used for applications in the transport sector, so Rahman & Chin developed an integrated framework for strategic performance evaluation of sustainable urban transport. They state that an examination of the consistency of the performance obtained from BSC with the real-life in-depth review for all indicators indicates that an effective evaluation of sustainability performance in urban transport can be achieved by using a BSC. This BSC is not used in this research, but can be included in the framework. Further research is required to indicate whether the BSC is useful in site selection studies.

Figure 30 indicates the performance of different MCA methods on sustainability assessments (Cinelli et al. 2014). Two methods from this figure will be described and applied: Weighted Summation (variant of the MAUT-method) and the ELECTRE-1 method. These methods are chosen because of their transparency and relatively low complexity. Results of the two methods will be compared in order to say something about uncertainty.

MCDA methods performance with reference to the sustainability-related indicators: + = good, strength of the set of methods, ○ = intermediate, depends on the method within the set or the author's judgment – = poor, weakness of the set of methods.

Comparison criteria domain		Comparison criteria	MAUT	AHP	ELECTRE	PROMETHEE	DRSA
Scientific soundness	Related to input data	Use of qualitative and quantitative data	+ Possible[5,6,11]	+ Possible[5,6,11]	+ Possible[5,7,11]	+ Possible[1,5,7]	+ Possible[27,28]
		Life cycle perspective	+ Possible[4]	+ Possible[4]	+ Possible[4]	+ Possible[4]	+ Possible[25,27,28]
	Related to calculation method	Weights typology	– Trade-offs[1,3,4,7,8,9,10,11,12]	+ Importance coefficients[11] – Trade-offs[3,4,7,8,12]	+ Importance coefficients[3,4,7,8,11,12,13]	+ Importance coefficients[4,7,12,15,16,17] – Trade-offs[8,14]	+ Not needed[27,28]
		Threshold values	– Not possible[5,8] + Possible[6,18]	– Not possible[5,6]	+ Possible[1,5,7,11,12,13,15]	+ Possible[1,5,6,7,10,12,15]	+ Possible, obtained from the decision rules[25,26,28]
		Compensation degree	– Full[1,2,3,5,7,8,9,12]	– Full[2,3,5,7,8,12]	+ Null[1,2,3,5,7,12,13] / ○ Partial[1,2,8]	○ Partial[1,5,7,8] – Full[2]	+ Null[26]
		Uncertainty treatment/ Sensitivity analysis	+ Possible[4,5,6,7,10,11]	+ Possible[9,20,21] ○ Partially possible[4,5,6]	+ Possible[4,5,7,13]	+ Possible[4,5,7,10,13,19]/ ○ Partially possible[6]	+ Possible[28,29,30,31]
		Robustness	+ No rank reversal is possible[5,8]	○ Rank reversal can occur[5,8]	○ Rank reversal can occur[5,8]	○ Rank reversal can occur[5,8]	○ Possible for the choice and ranking problems[27,28]
Feasibility		Software support and graphical representation	+ Software available with some graphical capabilities [5,6,11,19,20]	+ Software available with good graphical capabilities [5,6,9,11,19,20,21]	○ Software available, but with poor graphical capabilities[5,13,20,22]	+ Software available with good graphical capabilities[5,6,15,19,20,23]	○ Software available, but with poor graphical capabilities [33, 34]
		Ease of use	+ High[6,19] – Low[7,8]	+ NHigh[6,19] ○ Medium[5] – Low[7]	–Low[1,4,5,7,8,11]	○ Medium[1,5,6,7,8,19,23]	+ High[25,26,27,28]
Utility		Learning dimension	– Difficult[5,6]	– Difficult[5,6]/ + Possible[24]	–Difficult[5]	+ Simple with scenario analysis[5,6,23]	– Difficult[31,32]

[1]: (Benoit and Rousseaux, 2003), [2]: (Teghem et al., 1989), [3]: (Munda, 2005), [4]: (Belton and Stewart, 2002), [5]: (Antunes et al., 2012), [6]: (Buchholz et al., 2009), [7]: (Polatidis et al., 2006), [8]: (Munda, 2008), [9]: (De Montis et al., 2000), [10]: (Raju and Pillai, 1999), [11]: (De Montis et al., 2005), [12]: (Rowley et al., 2012) [13]:(Figueira et al., 2005b); [14]: (De Keyser and Peeters, 1996); [15]: (Brans and Mareschal, 2005); [16]: (Brans et al., 1986); [17]: (Le Teno and Mareschal, 1998); [18]: (Danielson et al., 2007); [19]: (Linkov and Moberg, 2012); [20]: (Weistroffer et al., 2005); [21]: (InfoHarvest, 2014); [22]: (Merad et al., 2013); [23]: (Geldermann and Zhang, 2001); [24]: (Fernandez, 1996); [25]: (Slowinski et al., 2009); [26]: (Roy and Słowiński, 2013); [27]: (Greco et al., 2001b); [28]: (Slowinski et al., 2012); [29]: (Greco et al., 2001a); [30]: (Dembczyński et al., 2009); [31]: (Błaszczyński et al., 2013); [32]: (Szelag et al., 2013); [33]:(Slowinski and Blaszczynaki, 2014); [34]: (Slowinski and Szelag, 2014).

Figure 30: Performance of different MCA's on sustainability assessments (Cinelli et al., 2014)

Weighted summation

The weighted summation aggregation method can be used to address problems that involve a finite and discrete set of alternatives that have to be evaluated based on conflicting criteria. Weighted summation is a compensatory method, which means that 'bad' criterion scores can be compensated by 'good' scores. The procedure for applying the weighted summation aggregation method (van Herwijnen, n.d.) will be as follows (comparable with the procedure mentioned in 5.3.1):

1. Definition of alternatives: identify the alternatives which are to be compared with each other.
2. Selection and definition of criteria: identify the effects or indicators relevant for the decision.
3. Assessment of scores for each alternative: assign values to each effect or indicator for all alternatives.
4. Standardization of the scores in order to make the criteria comparable with each other.
5. Weighting of criteria, in order to assign priorities to them.
6. Ranking of the alternatives: a total score for each alternative is calculated by multiplying the standardized scores with its appropriate weight, followed by summing the weighted scores of all criteria.

It should be noted that the first three steps are common in most MCA methods. Steps four to six are specific actions for the weighted summation method.

Electre-1 analysis

At the heart of the Electre method is an ongoing pairwise comparison of the scores per effect. This method uses the same standardized impact matrix (section 6.3.2) as the weighted summation method. Firstly, a concordance matrix is set up which indicates which alternative scores as well or better than another one for every criterion. For these alternatives, the weights are summed up and put in the concordance matrix. Subsequently, the net-concordance dominance index for every alternative is calculated. The higher the net-concordance index, the better (Janssen & van Herwijnen, 2007). The method is relatively straightforward, and in theory only suitable for quantitative scores, however also applicable on qualitative scores by standardization.

5.4.2 *Determination of selection criteria*

Evaluation of possible deep sea port sites will be carried out based on site selection criteria. The suitability of the selection criteria should be tested before using them in decision-making. In literature, two suitable methods for this test are found. Schipper et al. (2017) use four quality conditions for testing suitability of key performance indicators (KPI's) in sustainable measures. These KPI's are e.g. employment, air quality and port cargo growth, which can be compared with selection criteria often used in selection methods. The four quality conditions are:

a. **Responsiveness**: a KPI must detect environmental, social or economic changes in a timely way.
b. **Specificity**: the cause-effect relationship of the KPI must be primarily responsive to human activity and show low responsiveness to other causes of change.
c. **Accuracy**: tests whether the results of the KPI are consistent for the port management plans when the KPI is used
d. **Availability of data**: the KPI represented through data should be based on existing international, historically available time-series of data to allow realistic objectives to be set.

Van der Kleij, Hulscher & Louters (2003) also describe a number of quality conditions that a set of criteria has to satisfy, in their research on comparing uncertain alternatives for a possible airport island location in the North Sea. Van der Kleij et al. (2003) state that the most important quality conditions are that the selection criteria should be:

a. **Minimal & complete**: all aspects should be considered, non-relevant aspects should not be included and aspects of the selection problem should not be considered twice
b. **Not redundant**: effects which are equal for all alternatives should not be considered, and effects which are too small to generate a significant difference can be omitted

For determination of the site selection criteria in this research a combination of the abovementioned quality conditions will be used. Covering all aspects of deep sea port site selection is impossible in this relatively small site selection research, and because of the level of complexity of data gathering in Myanmar, the availability of data is considered to be of great importance. Two quality conditions will be used for this research:

1. Availability of data: if problems arise concerning availability of data, selection criteria can be altered
2. Not redundant: the limited amount of selection criteria should deliver significant difference in scoring

The quality criterion 'availability of data' is used in consultation with colleagues from Arcadis Myanmar and by evaluating the presence of data of these criteria in the most important and extensive sources: (JICA, 2014), (JICA, 2017), (IADS consortium, 2017), (Dutch Maritime Network, 2016). The quality criterion 'not redundant' is used after a first scoring of the alternatives. After scoring, criteria might need altering to increase the differences between alternatives.

The selection criteria are determined based on the stakeholder consultations, reference projects from Arcadis, transportation experts from Arcadis, and relevant literature. The enumeration on the next page shows the six selection criteria derived for this research.

The origin of the selection criteria 1. Environmental impact, 2. Social & political impact, 3. Economic impact is purely based on the sustainable port development definition in section 2.3.7, with the underlying Triple Bottom Line division. The sub-criteria under these main criteria are based on stakeholder consultations, and Arcadis references. For example: mangrove areas are deteriorating quickly and conservation is given high priority by the government. (Forced) resettlements are occurring at SEZ's in Myanmar which cause human rights violations (International Commission of Jurists, 2017) and are therefore chosen as selection criteria. Attraction to investors is of great importance as Myanmar suffers from low investment attractiveness, and the country fully depends on external financing of deep sea port projects.

The origin of selection criterion 4. 'Adaptivity', is based on the Adaptive Port Planning philosophy, discussed in section 2.3.5. Selection criterion 5. 'Logistics cost and construction cost' is based on the stakeholder consultations, and the generic consideration that costs are important, especially in countries with limited equity for transport infrastructure. Selection criterion 6. 'Feasibility and schedule' is determined during personal communication with C. Parkinson & J. Beard (2017), which is important because Myanmar needs a deep sea port site which can be developed relatively quick, concerning the expected future congestions. The main selection criteria and corresponding sub-criteria for application in the MCA are as follows:

1. Environmental impact

- **Mangroves**: impact of the proposed port location on mangrove forests and saltmarshes
- **Protected areas**: proximity of the proposed port location to protected natural areas or wildlife species
- **Dredging**: amount of construction and maintenance dredging at the proposed location

2. Social and political impact

- **Resettlements**: amount of villages and people that have to be relocated for the port development
- **Labor availability**: available workforce and population in the proximity of the proposed location
- **Accordance to policy**: accordance of the proposed port development to national development plans
- **Tourism**: to what extent has the proposed port development a positive or negative impact on tourism?

3. Economic impact

- **Attraction to investors:** attractiveness of the proposed location to investors, loans and funding
- **Fisheries:** impact (both positive and negative) of the proposed location on coastal fisheries
- **Impact on economic inequality:** influence of proposed location on economic inequality (cities/regions)
- **Contribution to the Sustainable Development Goals:** extent of contribution to SDG's

4. Adaptivity

- **Future expandability:** adaptivity of the proposed location to future changes (cargo type, growth)

5. Logistics cost/construction cost

- **Sea, inland water, rail, road:** availability and quality of these different transport modes
- **Water depth, shelter:** large water depths are needed for big ships and shelter can be necessary against waves

6. Feasibility/schedule

- **Timespan:** estimated required time for the proposed location before being operational
- **Level of complexity:** occurring level of complexity during construction at the proposed location

In the next section, determination of the weight factors for these six selection criteria in a multi-stakeholder workshop is described. Ideally, selection criteria are also determined in cooperation with stakeholders however, this turned out to be impossible because only one short workshop could be arranged. Therefore priority was given to determine the weights of the criteria in the workshop. Nonetheless, to be able to say something about agreement of the stakeholders with these criteria, the criteria are validated on importance and usability in a questionnaire. Results of this validation can be found in Table 30, in which the column 'yes' means: stakeholder values the specific sub-criterion as useful and important. The column 'no' means: stakeholder does not value the specific sub-criterion as useful and important. The total number of questionnaires was nineteen, and in some cases stakeholders did not check every sub-criterion.

Table 30: Site selection criteria validation by stakeholder

Criterion	Yes	No	%		Criterion	Yes	No	%
1. Environmental impact					**4. Adaptivity**			
- Mangrove impact	14	2	74		- Potential for future expanding	18	1	95
- Protected habitat/areas	15	1	79		**5. Logistics/construction cost**			
- Dredging amount	17		90		- Sea/Inland water/Rail/Road	18		95
2. Social & political impact					- Water depth/shelter	16		84
- Resettlements villages/people	16		84		**6. Feasibility/schedule**			
- Labor availability/workforce	14	1	74		- Timespan for implementation	15	2	79
- Accordance to policy/masterplan	17		90		- Level of complexity	14	2	74
- Tourism impact	9	6	47		- Legislative difficulties	14	2	74
3. Economic impact								
- Attraction to investors	17		90					
- Fishery impact	13	2	68					
- Impact on economic inequality	14	1	74					
- Sustainable Goals contribution	19		100					

From this validation it can be concluded that the average agreement for the predefined selection criteria is 81%. Only the sub-criteria ‘Tourism impact’ scores relatively low, which asks for reconsideration of this criterion. The criterion ‘’Contribution to Sustainable Development Goals’’ is complex. All stakeholders agreed on the relevance of this criterion, however it became clear that assessing this criterion is too complex for this research. This is emphasized by Greenport (2017), in their article on the relevance of sustainable development goals (SDG) for sea ports. Greenport state that the port sector is not represented by a standalone SDG. It is ‘socialized’ across several SDG’s. According to Greenport, ports have at least this three-fold role:

1. Ports are inherently well positioned to contribute to societal development through job and wealth creation associated with facilitating trade and infrastructure investment.
2. As an integral part of many cities and often located in ecologically valuable areas, ports have a responsibility to run business with no harm to (and preferably enhancement of) the local community and environment.
3. Increasing supply chain sustainability requirements driven by consumers, means ports will increasingly be expected to contribute to the sustainable development agenda.

Greenport mentions ports should do something, but it is still unclear to which goals and targets ports should align with, and the determination of relevant SDG’s is variable and specific to each business model. Figure 31 shows the seventeen SDG’s.

Figure 31: Sustainable development goals (UN, 2018)

For this research it is decided that it is impossible to incorporate and measure all 17 SDG’s, however some SDG’s were already indirectly included in the selection criteria and in the ecosystem-tool, and the three-fold role as stated by Greenport is also divided in the tool and the selection criteria:

- SDG 12, 13, 14 & 15 are included in the main criterion ‘Environmental impact’
- SDG 1, 8 are included in sub selection criteria ‘Labor availability/workforce’
- SDG 1, 2, 8 & 14 are included in sub selection criterion ‘Fishery impact’
- SDG 10 is assessed by sub selection criterion ‘Impact on economic inequality’
- SDG 2, 6, 7, 13, 14 & 15 are assessed by the ecosystem tool in section 6.3.6
- SDG 9 which is included in the whole port development process

Sustainability assessment is therefore fully based on the ecosystem-tool and the environmental, social and economic impact of the specific sites, in which the SDG’s are reviewed. There is insufficient data and knowledge to assess all SDG’s. Contribution to the Sustainable Development Goals will therefore be removed from the selection criteria as separate criterion, however is partly assessed by other criteria as mentioned in the above enumeration. Also Ligteringen (2017) mentions the connection of the SDG’s with port development and operations, varying from weak to strong. A strong connection is said to be present between ports and SDG’s 7, 8, 9, 14, & 15, which can all be found in the enumeration above.

5.4.3 *Multi-stakeholder workshop*

Although organizing workshops seems like a pragmatic activity, many articles have been written about problem structuring methods or game-structuring approaches used in complex decision-making situations. According to Cunningham et al. (2014), problem- or game structuring methods are uniquely suitable for analyzing strategically complex problems. A subset of problem structuring methods exist which focus specifically on structuring decision processes by which multiple actors debate. Some of these methods include: analysis of options, conflict analysis, exchange modelling, hypergame analysis and the theory of moves. Cunningham et al. (2014) define game-structuring techniques as *''a set of applied methods for finding strategic elements that shape decision processes in a complex problem setting. Such elements include, but are not restricted to, players, actions, payoffs, outcomes and information.''* These game structuring methods are widely applicable, however Cunningham et al. focus primarily on their use to support live interaction and problem solving with actors in a workshop setting.

On 19 December 2017, a workshop titled ''Capacity building on deep sea port development opportunities in Myanmar'' was organized on behalf of Arcadis, the Embassy of the Netherlands and Delft University of Technology. Figure 32 presents the agenda of the workshop, which consisted of two interactive sessions.

Time	Agenda item	By
9:15	Registration of participants	
9:30	Opening remark	Embassy of the Netherlands Ms. Tanya Huizer
9:40	Introduction: objectives, benefits, subjects	Mr. Michel Oosterwegel
9:50	Session 1: Valuation of ecosystem services and discussion: which services are valued most important and what is the impact of port developments on the ecosystem?	All participants
10:30	Coffee break & group photo	
10:45	Presentation of key findings research on deep sea port development	Mr. Michel Oosterwegel
11:00	Session 2: Valuation of site selection criteria by means of pairwise comparison and discussion. Introducing a tool which can be used by all participants in future projects.	All participants
11:45	Short questionnaire	All participants
12:00	Closing remark	Mr. Michel Oosterwegel
12:15	Lunch	All participants

Figure 32: Schedule multi-stakeholder workshop

The first interactive session involved valuation of ecosystem services, in order to determine values of the Myanmar stakeholders, and to show the impacts (both positive and negative) of port development on the ecosystem. The second interactive session focused on the determination of the weight parameters for the selection criteria defined in section 5.4.2.

The main purpose of the workshop was supporting the stakeholder-inclusive approach in this research. A stakeholder-inclusive approach can help in achieving sustainable development, as described in section 2.3.4, and besides helps in obtaining data for framework development and site selection. A detailed description of the workshop and the workshop results (including questionnaire) can be found in Appendix I. Important for this section is the determination of the weight parameters for the selection criteria. Determination of the weight parameters is carried out by means of a pairwise comparison, which is discussed in section 5.4.1. During the workshop, stakeholders were asked to use the spreadsheet in Figure 33. For every pair of criteria, they had to decide on the importance, on a scale of 1 to 9.

Which criterion with respect to *Deep sea port site selection* is more important, and how much more on a scale 1 to 9?

	A - Importance - or B?			Equal	How much more?
1	◉ Environmental impact	or	○ Social & Political impact	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
2	◉ Environmental impact	or	○ Economic impact	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
3	◉ Environmental impact	or	○ Adaptivity	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
4	◉ Environmental impact	or	○ Construction cost & logistics cost	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
5	◉ Environmental impact	or	○ Feasibility & schedule	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
6	◉ Social & Political impact	or	○ Economic impact	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
7	◉ Social & Political impact	or	○ Adaptivity	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
8	◉ Social & Political impact	or	○ Construction cost & logistics cost	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
9	◉ Social & Political impact	or	○ Feasibility & schedule	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
10	◉ Economic impact	or	○ Adaptivity	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
11	◉ Economic impact	or	○ Construction cost & logistics cost	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
12	◉ Economic impact	or	○ Feasibility & schedule	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
13	◉ Adaptivity	or	○ Construction cost & logistics cost	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
14	◉ Adaptivity	or	○ Feasibility & schedule	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
15	◉ Construction cost & logistics cost	or	○ Feasibility & schedule	◉ 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9

Figure 33: Pairwise comparison tool used during the workshop

The tool calculated the weight parameters, forming the basis for a discussion on priorities. An important assumption for this tool is the nine-point semantic scale, which indicates: 1 = equal importance, 3 = moderate importance, 5= strong importance, 7 = very strong importance, 9 = extreme importance (Saaty, 1988). The pairwise comparison provided a clear and concrete method for prioritization of selection criteria. The results of this pairwise comparison for every stakeholder can be found in section 6.3.1.

5.4.4 *Ecosystem services & interrelations tool*

This section describes the application and evaluation of ecosystem services in the site selection process and in the framework. It is chosen to use the concept separately instead of integrating it into the MAMCA, for the following reasons:

- As explained later on in section 7.1.1, it is more useful to apply the Ecosystem Services in the design of a port, and the tool presented upon in this section points out critical points for specific locations where port development may deliver and strengthen a positive impact or where negative impacts should be minimized.
- Evaluating every Ecosystem Service in a MAMCA asks for comprehensive data gathering for all sites included in the MAMCA. It is not considered to be feasible, and evaluating the Ecosystem Services qualitative for 2 specific sub-regions is less time consuming and already provides useful results for the Ecosystem-Based design.
- So emphasis is put on identifying positive interrelations between port development and Ecosystem Services in a specific sub-region which can be strengthened on the one hand, and identifying negative interrelations which should be mitigated or even removed. These interrelations are subsequently used to design the port in such a way it strengthens positive impact and minimizes negative impacts.

For this section, reference is made to De Boer (2016), who developed an ecosystem-based framework for sustainable marina development. An important aspect of this framework is the ecosystem assessment, aimed at assessing the interaction between a marina and its natural environment. De Boer (2016) developed the ''marina-ecosystem interrelations tool'', which provides complete insight on the interactions between a marina and its natural environment. The tool is generically applicable and delivers insight in a port's integration into the environment by getting an overview of all interrelations. A certain port element (construction of port elements like quays and use of these elements like mooring) may have predominantly positive or negative effects on an ecosystem service, however from an ecosystems perspective, an ecosystem service can have negative or positive effects to a port element as well. The tool is presented as a matrix, with the ecosystem services on the horizontal axis and the port functions on the vertical axis. For each combination between a port function and an ecosystem service, the relation is indicated twice. Firstly, the impact of the port element or function on the ecosystem service is evaluated, and secondly the impact of the ecosystem service on the port element or function is evaluated. Each interrelation is ranked by using a ranking range from double negative to double positive. These rankings are based on available knowledge and expert judgement, and can be improved based on experience and knowledge building.

In order to deal with the impacts of specific deep sea port sites on the ecosystem, the marina-ecosystem interrelations from G. de Boer (2016) tool will be adapted towards a ''deep seaport-ecosystem interrelations tool'' (for brevity: ecosystem tool) and uses similar port elements and ecosystem services. The tool is suited to use in this research and more general in location studies to assess impacts (both positive and negative) on the ecosystem, however it should be mentioned that the elaboration of the method in this research is not as extensive as in De Boer (2016). The following ecosystem services will be included in the ecosystem tool, based on UNEP 2011 and corresponding to the discussed ecosystem services in the multi-stakeholder workshop:

1. **Flood protection:** mangroves, saltmarshes, and tidal flats act as natural filters, trapping harmful sediments and excessive nutrients. Offshore reefs create sand and protect the shoreline from severe storms.
2. **Recreational possibilities:** Scenic coastlines, islands, and coral reefs offer recreational opportunities, such as scuba diving, sea kayaking, sailing, and use of beaches.
3. **Wildlife/biodiversity:** Estuarine seagrasses and mangroves provide nursery habitat for commercial targeted fish and crustacean species. Healthy coral reefs are hotspots of marine biodiversity and offer sources for medicine.
4. **Fresh water:** Healthy rivers provide drinking water for communities and water for agriculture.
5. **Erosion/sedimentation regulation:** Streamside vegetation on rivers or estuarine areas reduces erosion and traps pollutants.
6. **Seafood/fisheries:** Sustainable fisheries provide food, create jobs and support local economies.
7. **Fuel/offshore energy:** Offshore and sustainable energy (wind, tidal, solar) provides power to support coastal development.
8. **Climate regulation:** Marine ecosystems including seagrasses, mangroves, and saltmarshes act as carbon sinks, reducing greenhouse gasses. The gasses mainly originate from vessels and construction. Besides climate regulation by using carbon sinks, greenhouse gas reduction is also included in this ecosystem service which can be achieved by construction and maintenance minimization.

In the marina-ecosystem interrelations tool from de Boer (2016), the following marina elements are evaluated:

1. **Marina:** Structural elements (quay walls, breakwaters, fixed jetties)
2. **Marina:** Floating elements (floating breakwaters, pontoons)
3. **Marina:** (Maintenance) dredging of marina basin and navigation channel
4. **Marina:** Bottom structures (jetty anchoring, navigation marks)
5. **Marina:** Construction and maintenance
6. **Marina use:** Boat presence (moored boats, engines, boat wastes)
7. **Marina use:** Onshore activities (noise, stormwater run-off, nutrients)
8. **Marina use:** Social and community places (education center, yacht club)
9. **Marina use:** Marine activities (sailing, tour operating, speeding, fishing)

A deep sea port shows many similarities with respect to port elements and operational aspects, however some elements such as floating elements and social/community places are often not present in deep sea ports. One important adjustment has been made with respect to the port elements concerning dredging. A distinction has been made between OPEX and CAPEX dredging (instead of (maintenance) dredging as used by G. de Boer) because the tool is evaluated for different locations. Between locations, substantial differences exist between the impacts of OPEX and CAPEX dredging. For example, a river mouth region probably has significant CAPEX dredging already, but it also has the largest OPEX dredging due to large amounts of sediments disposed near the river mouth. A win-win situation can be realized when dredged material is put back into the system. (Relatively deep) mangrove areas experience less CAPEX and OPEX dredging than shallow river mouth areas. The deep seaport-ecosystem interrelations tool will use the following seaport elements and operations:

1. **Deep seaport:** Structural elements (quay walls, breakwaters, fixed jetties)
2. **Deep seaport:** CAPEX dredging of approach channel and basins
3. **Deep seaport:** OPEX dredging of approach channel and basins
4. **Deep seaport:** Bottom structures (jetty anchoring, navigation marks)
5. **Deep seaport:** Construction and maintenance
6. **Operations:** Vessel presence (mooring, wastes, engine nuisance)
7. **Operations:** Onshore activities (loading/unloading, industries)
8. **Operations:** Marine activities (fishing, tugboats)

The beforementioned set of ecosystems and the abovementioned elements lead to the matrix in Figure 34.

			1.	2.	3.	4.	5.	6.	7.	8.	9.
			Provisioning			Regulating & supporting				Cultural	
		Horizontal: Ecosysem services (UNEP, 2011) Vertical: Deep sea port elements	(Sea)food provision	Fresh water storage and provision	Offshore energy	Flood protection	Erosion and accretion regulation	Wildlife habitat and biodiversity	Climate regulation	Recreation and (eco-tourism)	Aestethic and visual aspects
1.	Deep seaport	Structural elementes: quay walls, breakwaters, jetties									
2.		CAPEX dredging of approach channel & basins									
3.		OPEX dredging of approach channel & basins									
4.		Bottom structures: jetty anchoring, navigation marks									
5.		Construction & maintenance									
5.	Operations	Vessel presence: mooring, wasters, engine nuisance									
6.		Onshore activities: loading, unloading, industries									
7.		Marine activities: fishing, tugboats, sailing									

Figure 34: Deep seaport-ecosystem interrelations matrix

The matrix will be evaluated for different deep sea port sites categorized in two sub-regions 'mangroves' and 'river mouth', in order to assess differences in impacts of deep sea port developments at different locations, and to incorporate ecosystem-based management into the site selection process. This ecosystem assessment is elaborated upon in section 6.3.6.

5.4.5 2-step filter process & showstoppers

The last aspect of the proposed framework in section 5.1 which requires motivation is the 2-step evaluation process with 2 filters. Reference is made to Figure 5: Funnel model on site selection (Glatte, 2015), Figure 9: Initial sustainable site selection framework, Figure 26: 2-step evaluation process, and Table 7: Process of site selection as provided by Arcadis. The funnel model in Figure 5 suggest a division between longlisting and shortlisting, which was also recommended in the initial framework of this research. PIANC also distinguishes between a long list and a short list of possible sites in Figure 26 and Arcadis uses this in practice as well.

The main motivation for division between a long list and a short list is the fact that evaluating 10 or 15 sites in a comprehensive way is too time consuming, and by means of expert judgement or a simple evaluation method a substantial amount of possible sites can already be dropped from the list. This first step of narrowing down from a long list to a short list can be carried out based on different criteria, which is described in section 6.2. After application of this first filter, it is sometimes possible to indicate on which criterion or criteria the remaining sites differ substantially (e.g. costs, resettlements etc.). If this criterion is clear, this can be seen as a decision turning point which determines if alternative A, B or C will be ranked number 1. It can be helpful to focus on this decision turning point first before applying the whole MCA/MAMCA method.

Another motivation for applying filters are the regulatory requirements. If sustainability is a must-have criterion, it can be used in a filter so that we end up with alternatives in the second filter which meet a certain required level of sustainability. In this way, the first filter can be adapted to the political priorities, or to constructional aspects. A first filter based on sustainability can be carried out by using the ESF from the Worldbank (section 2.3.6), the outcomes of the ecosystem-tool (section 6.3.6), or the impact on the sustainable development goals.

5.4.6 Showstoppers: political situation, budget, ESIA

Carrying out the site selection process according to the framework will not always proceed as straightforward as desired. Depending on the applied filters and points of view of decision-makers, unexpected criteria may pop up which cause rejection of a site in the short list. These criteria, for which it is not possible to reduce the effect by simply investing extra money, are called 'showstoppers'. Sometimes these criteria are known upfront, but this is not always the case. Three possible showstoppers came forward during the case study:

- **Political situation**: An instable political situation in the proximity of a specific site causes hindrance in obtaining foreign investments or loans from development banks. Besides, problems with human rights in those areas strengthen this hindrance even further.
- **Budget**: Some sites may be rejected after a first rough cost estimation. An offshore port, to be built on silt for example is a very costly operation, and in some situations it can be stated that the project will become too expensive.
- **Environmental & Social Impact Assessment (ESIA)**: Environmental and Social Impact Assessments have to be conducted in deep sea port developments. Negative outcomes of these assessments can cause rejection of sites because permits cannot be obtained.

5.5 Validation of proposed framework

Before application of the site selection framework, a validation is carried out by means of expert consultation. In general the experts agreed on the framework, however they were of the opinion that it could be less extensive, and some recommendations were given. The framework as presented in sections 5.1, is proposed to three experts from Arcadis, a professor of Transport & Logistics from Delft University of Technology, and a port development expert from Deltares. A discussion on applicability, shortcomings and improvements led to the following results:

Arcadis: A. Dekker (26-2-2018)

- Try to elaborate on added value opportunities for Myanmar. Creation of added value leads to industrial activities, and location of specific industrial activities can influence site selection of deep sea ports because the ports need to be where the industrial activities are centered.
- Proximity to cyclone areas and seismic zones should be incorporated in the site selection process.
- Location needs space and possibilities for facilitation of country-specific industry.

Arcadis: J. de Groot (27-2-2018)

- Concerning site selection in Myanmar, one of the most important aspects is an inexpensive first stage, and possibilities for phased development.
- Besides the depth and length of the approach channel, required width can be an important constraint as well, and should be considered in an early stage.
- A first sediment analysis can be included, based on historical Google Maps. This is often used as a first simple method to obtain information about stability of the coastline.
- Overall: framework can be applied, but can be less elaborate. For the design phase: try to show zoning of the port area, hinterland connections, marine infrastructure and breakwater considerations.

Arcadis: C. Beenhakker (27-2-2018)

- A primary objective during site selection is a stable coastline and deep water. On the other hand, large water depths mean large costs for harbor protection by breakwaters.
- According to C. Beenhakker, transshipment should not be an objective of Myanmar because of the less favorable location off the main shipping lines, compared to Sri Lanka and Malaysia.
- Nowadays costs are always priority number one, and environmental considerations second. Especially development banks have stringent environmental demands.
- For a conceptual design, zoning of the area is most important. Zoning is mainly a consideration between empty areas and required labor force, however a port is always centered around economic centers.

Delft University of Technology: B. van Wee (1-3-2018)

- Try to make MCA stakeholder-specific in a Multi-Actor Multi-Criteria Analysis (MAMCA). In a MAMCA, different weights are attached to different stakeholders.
- It may be interesting to evaluate different filter techniques: e.g. a first filter based on sustainability, a second one based on showstoppers, and if necessary a MCA/CBA for final evaluation
- A full MCA might not be necessary if the differences between alternatives are relatively large after a first filter. In this case, mention the decision turning point between alternatives.
- With respect to deep sea port locations, it is often quite easy to tell which locations have potential and which locations don't have potential. Use different filter techniques to filter out low potential locations with only a few simple parameters, instead of evaluating all alternatives with MCA techniques.

Deltares: W. de Boer (15-3-2018)

- Littoral sediment transport and the amount of required reclaimed land can be included in the first filter. Large amounts of littoral transport means large dredging expenses.
- Use iteration in the framework, after filter 1 or filter 2, it might become clear that excluded options have more potential than remaining options. Do not carry out site selection as a linear process.

5.6 Final framework for application

Based on the validation step in the previous section, the framework is enhanced and adapted:

- The Environmental & Social Framework from the World Bank should be incorporated in the financing possibilities in phase 1 of the framework, and can be the content of a filter (section 6.2).
- Added value opportunities on specific locations should be investigated during the requirements study.
- In phase 3 ''Site identification, evaluation & ranking'' first a sequence and the content of the filters should be determined (section 6.2), before carrying out the site selection.
- After filter 1, a Go/No-Go decision has to be made based on the outcomes of filter 1, and the differences between these alternatives. It should be known if a 'decision turning point' (key criterion which will determine the ranking between the sites after filter 1) is present.
- Instead of traditional MCA techniques, the MAMCA technique (Hadavi et al., 2018) includes an extra actor-layer which carries out a MCA for every actor.
- For the conceptual lay-out in this research, it is recommended to focus on four key considerations: terminal zoning & phased development, hinterland connections, marine infrastructure and breakwater requirements.
- In addition, sustainability will be included at four planning 'levels'.

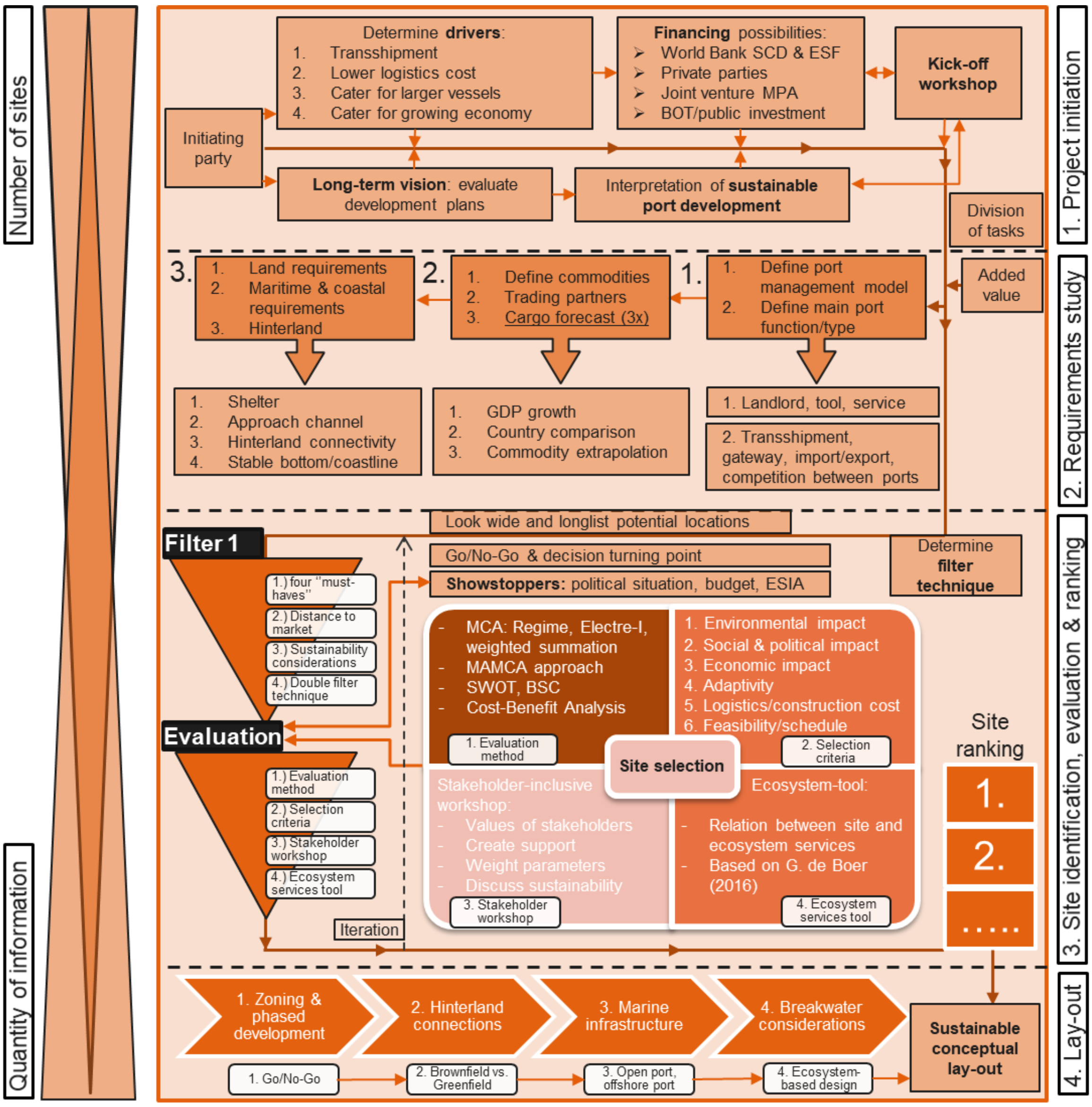


Figure 35: Final site selection framework after validation

6 APPLICATION OF FRAMEWORK TO THE CASE STUDY

The framework is improved and validated, and ready for application. Application of the framework to the case study should be defined in more detail. As mentioned in section 5.1, the framework is divided into four phases. The core of the framework is the third phase, which concerns the site identification, evaluation, and ranking. The first two phases 'Project initiation' and 'Requirements study' are included in the framework because this information is necessary before selecting the site. In general, this information is already acquired before site selection, but in this research these two phases are carried out because the information was not delivered by the client. Application of the framework in this chapter means application of the third phase, which will result in a ranking of deep sea port sites. For application, first filter 1 will be applied, which provides a short list based on the key criteria criteria land, depth, connectivity and shelter. Filter 1 can be evaluated in different ways, based on different priorities, as discussed in section 5.4.5. After filter 1, filter 2 concerns evaluating the short list with two types of multi-criteria analysis. After setting up the impact matrix, which serves as basis for both types of the MCA, a scenario-based ranking and sensitivity analysis will be carried out in section 6.3.5.

6.1 Filter 1: four must-haves

The long list which serves as input for filter 1 is determined based on engineering judgement and knowledge of Myanmar. Purpose is to look wide and prevent exclusion of potential sites. The long list can be set up based on the stakeholder consultations and the sites mentioned in the questionnaire (Appendix I). Besides, current ports and port developments in Myanmar indicate locations which are suitable for further port development. Table 31 shows the possible locations and the first filter criteria. These four criteria are crucial aspects of sites and some can be seen as 'showstoppers': criteria which cause rejection of the site if this criteria can't be met. In this site selection study, a filter with the four key criteria available land, connectivity, water depth and shelter is used because satisfying these criteria contribute to minimizing construction activities which minimizes both costs and impact on the environment.

Table 31: Filter 1: long list testing on four key criteria

Long list	**Available land**	**Connectivity**	**Water depth**	**Shelter**	Myanmar*
Sittwe					
Kyaukpyu					
Thandwe					
Danson Bay					
Nga Yoke Kaung					
Yangon offsh.					
Yangon nearsh.					
Thilawa					
Mawlamyine					
Dawei					
Myeik					Coral reefs
Kawthoung					

Available land and connectivity are considered as showstoppers. Lack of water depth and the absence of natural shelter are considered as disadvantages, however it may be possible to create sufficient water depth and shelter at reasonable costs. The following assumptions and measures are relevant for the four criteria.

- **Available land**: substantial empty and flat land should be present or possible to develop at reasonable cost
- **Connectivity**: at least two modes of transport are present on accessible terrain or possible to develop within 10 years at reasonable cost.
- **Water depth**: at least 12 m of water depth (and areas up to 16 m) should be available for the approach channel and basin in order to maintain acceptable amounts of maintenance and capital dredging.
- **Shelter**: natural possibilities for sheltering such as lagoons or islands are a large advantage. Possibilities for natural sheltering are tested based on a dominant South-West wave direction.

To provide guidance with respect to Table 31, some motivation will be provided. Bad connectivity in Kyaukpyu, Sittwe and Thandwe (Northern coastal stretch of Myanmar) is caused by the Arakan Mountain Range which stretches from Bangladesh along the coast of Myanmar towards the Ayeyarwady delta (Figure 36). Roads are of low quality, and not suited for heavy duty transport. There is no inland water transport and railway transport possible. Besides, the Transport Masterplan (JICA, 2017) shows that few infrastructure developments are planned in this mountainous area.

Exceptions: The upper right column shows 'Myanmar*': as can be seen in the framework, two other Myanmar-specific showstoppers should be taken into account. The political situation and the required budget. Sittwe and Kyaukpyu are located in the middle of Rakhine State, where a humanitarian crisis is going on. These areas cause great uncertainties with respect to investments and future political situation, and are therefore excluded from the long list. Also because of violation of human rights in Kyaukpyu (International Commission of Jurists, 2017), this location is excluded. Lastly, Thilawa is excluded from further evaluation because this location is a river location with continuous dredging activities, which is the problem statement of this research. Based on Table 31, stakeholder preferences (section 5.2) and expert judgement, the following short list will be evaluated in filter 2: Pathein, Yangon, Mawlamyine and Dawei, indicated on the next pages. Figure 36 provides an overview of all sites from the long list.

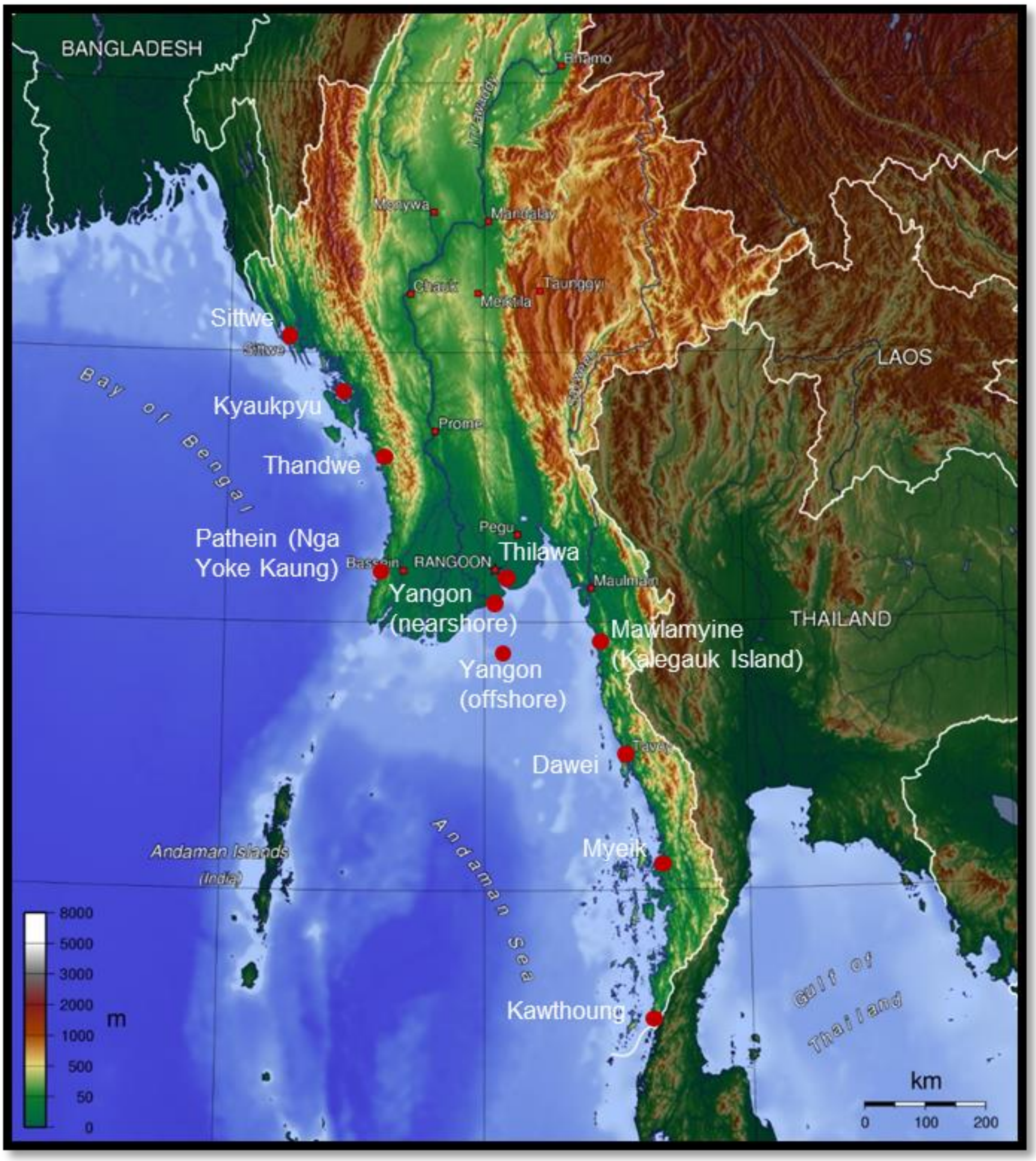


Figure 36: Overview of long list sites

1. Pathein (Nga Yoke Kaung or Danson Bay)

These locations have quite similar characteristics and are located approximately 30 kilometers away from each other. They offer sufficient available land and besides a road network, a rail network is planned from Yangon to Pathein in the coming years, and the. Danson Bay and Nga Yoke Kaung area both have natural depths of approximately 10 meter, however dredging costs are most likely to be reasonable because of the sandy soil. With respect to sheltering, both locations are situated in a natural bay which helps in protecting the future port.

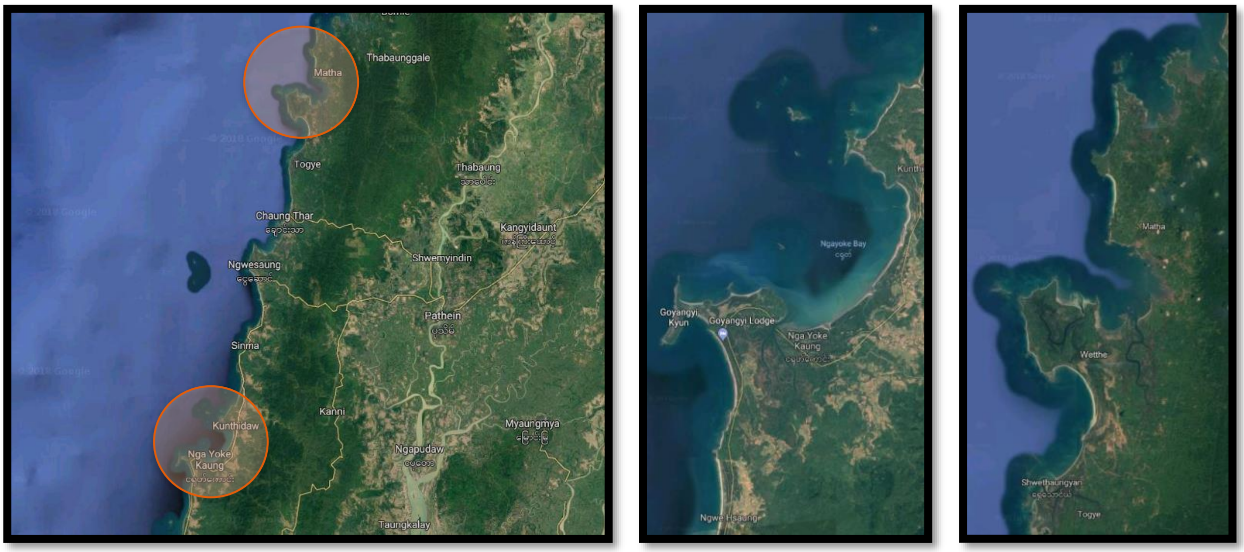


Figure 37: Proposed Pathein sites (left small picture Nga Yoke Kaung, right small picture Danson Bay)

2. Yangon area (Yangon nearshore or offshore)

With respect to Yangon as possible site, a nearshore (Figure 38) and an offshore option is proposed. Nearshore and riverine options near Yangon suffer from small natural water depths and large sedimentation rates. This makes these options less suitable for deep sea port development. Yangon is the largest city and the main economic center, and strong pressure is put on Yangon as deep sea port location. Therefore the nearshore option will be evaluated in the site selection process, to show its relevance and performance. Besides, an offshore option is proposed (discussed in more detail in section 7.2.2) to tackle the sedimentation and depth problems. This offshore option does not have available land, connectivity and shelter yet, but will proceed to the next filter because of the importance of Yangon as possible port development site. The eastern side of the river mouth is chosen instead of the western side because the sediment transported from the Yangon river is directed towards the Western coastline into a funnel.

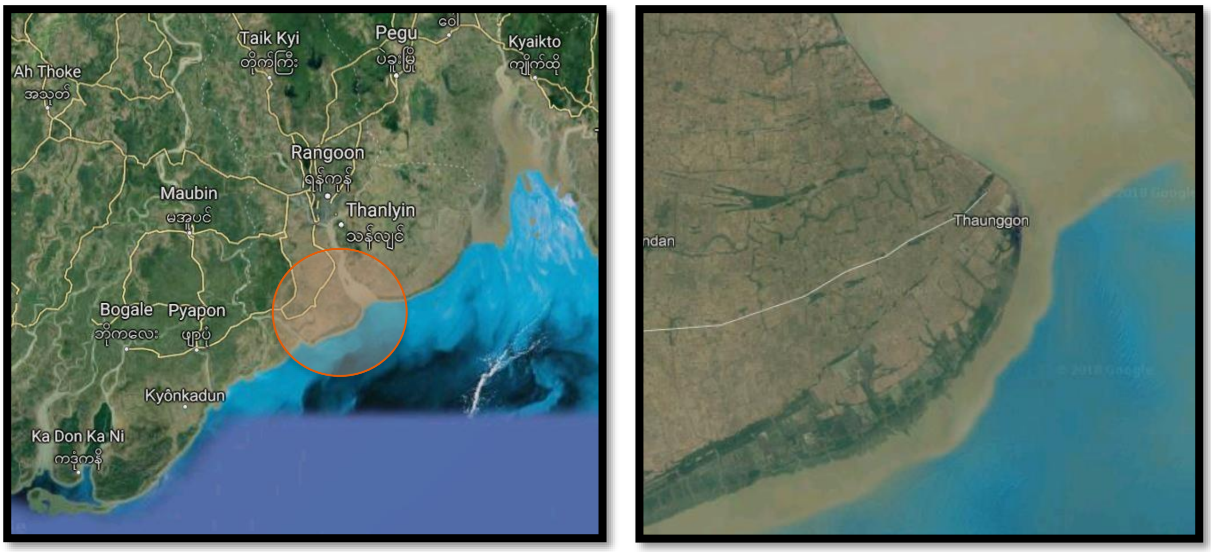


Figure 38: Proposed Yangon site (near shore at Eastern side of the river mouth)

3. Mawlamyine (Bilugyun Island or Kalegauk Island)

Near the city of Mawlamyine, several locations are possible and proposed, of which two will be discussed. Paik & Win (2016) mention two proposed locations, near Bilugyun Island and Kalegauk Island, which are shown in Figure 39. The locations near Mawlamyine are suitable for deep sea port development according to Table 31, however it is chosen to proceed only with the Kalegauk island option. The main reason for this decision is the presence of a tidal bore in the Sittaung river, near Bilugyun Island. In some cases, the area of the tidal bore reaches Bilugyun Island, which may cause problems relating to severe erosion, downtime of vessels or dangerous situations for vessels. Besides the presence of this tidal bore, Kalegauk Island offers possibilities for natural sheltering of the port. Sufficient land is available, and a road and railway network is available. Water depths of 12 m occur around Kalegauk Island.

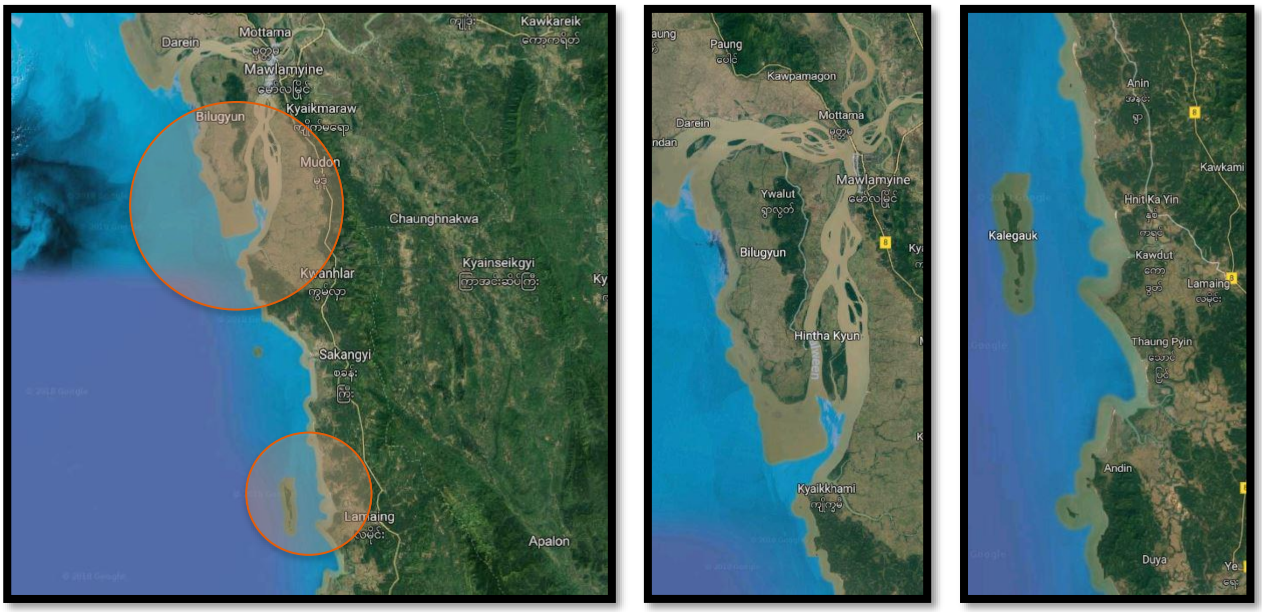


Figure 39: Proposed Mawlamyine sites (left small picture Bilugyun Island, right picture Kalegauk Island)

4. Dawei (at actual development site)

Dawei (Figure 40) is the only proposed site which experienced deep sea port developments so far. Because of financing problems, the project was on hold, and questions arose if Dawei is a good deep sea port location. Dawei will be evaluated in filter 2 because of the available land, connectivity by road and railway, and presence of natural depths up to 12 meter. This site does not provide possibilities for natural sheltering.

Figure 40: Proposed Dawei site (construction already started)

6.2 Filter 1: alternative filter methods

As mentioned in sections 5.4.5, different filter methods will be investigated, to create short lists which will be ranked afterwards. By doing so, considerations for choosing one alternative instead of another alternative can be derived, which may avoid time-consuming MCA's. Besides, emphasis can be given to different policy considerations like sustainability, World bank financing criteria, or constructional showstoppers.

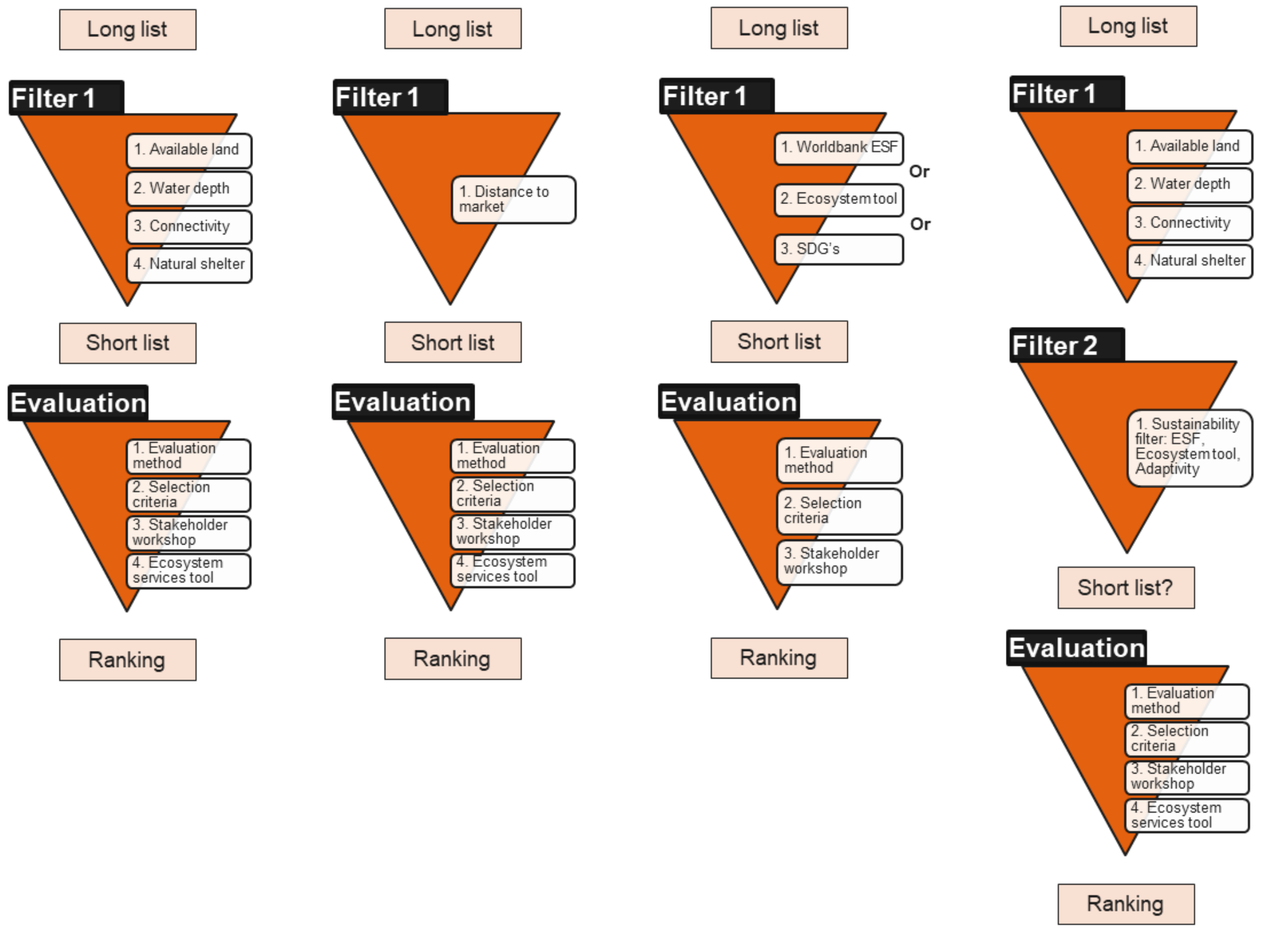


Figure 41: Different filter techniques for the evaluation phase of the site selection process

The standard filter technique is the left method in Figure 41, based on a first filter with the four showstoppers available land, water depth, connectivity, and the presence of available shelter. This filter can be extended by including the littoral sediment transport at the specific site.

The second filter technique in Figure 41 is based on a first filter with two aspects often described as most decisive for port development. This research focuses on a gateway port which requires that the hinterland should be close to the port development under consideration.

The third filter technique in Figure 41 is based on a first sustainability filter with the ESF (The Environmental & Social Framework) of the World Bank which elaborates on criteria which should be met in order to obtain loans from the development banks. Other options for the sustainability filter are the results of the ecosystem tool, the seventeen sustainable development goals or the adaptive aspects.

The fourth filter technique in Figure 41 is a three-step process in which a first filter is applied based on the four showstoppers, and a second filter is used based on sustainability.

In all filter techniques, the main idea is that a comprehensive elaboration of the evaluation step, with evaluation methods and stakeholder workshops, is only necessary if the first filter results in many alternatives which have small mutual differences based on the main criteria environmental impact, social & political impact, economic impact, adaptivity, logistics & construction cost, and feasibility/schedule. The choice for a specific filter can be based on different motivations, however the use of political considerations is recommended. As said, in this site selection study, a filter with the four key considerations available land, connectivity, water depth and shelter is used because satisfying these criteria contribute to minimizing construction activities which minimizes both costs and impact on the environment. Besides this filter, the 'distance to market filter' is used as a check to see whether this will lead to a different shortlist.

Filter 1: Distance to market

A port should be located close to the location where the cargo needs to be, and from where the cargo needs to be shipped. This lowers logistics costs and strengthens the competitive position of the port. Section 3.1 elaborated upon on the type of port, and it was concluded that this research focuses on a gateway port for facilitating and increasing the import and export cargo of Myanmar. Especially for these type of ports, where the imported cargo will be transshipped towards locations with the largest markets (large population, industries, large GDP), and where exported cargo comes from these same markets, proximity to these markets is crucial. Contrary to transshipment ports, for which proximity to main shipping routes is more important. Figure 42 shows the ten development corridors (clustered areas connected by infrastructure) as determined by MOTC and JICA (2017).

Development Corridor	Section	Code	2012 Population (,000)	% of National Population	2012 GRDP (Kyat billion)	% of National GDP
A. Central North-South Corridor	Yangon-Nay Pyi Taw	A1	11,714	41%	13,170	50%
	Nay Pyi Taw-Mandalay	A2	6,323		4,457	
	Mandalay - Myitkyna	A3	7,035		5,648	
B. East - West Corridor	Yangon - Hpa-An - Myawaddy	B1	14,052	28%	14,543	35%
	Mawlamyine - Dawei	B2	2,753		2,039	
C. Northern Corridor	Mandalay - Muse	C1	6,042	10%	4,503	10%
D. Mandalay - Tamu Corridor	Mandalay - Tamu	D1	8,722	14%	6,992	15%
E. Second East - West Corridor	Tachilek - Meiktila - Kyaukpyu	E1	10,636	17%	6,938	15%
G. East - West Bridging Corridor	Hpasawing - Pyay	G1	2,664	12%	1,727	11%
	Loikaw - Magway	G2	4,767		3,214	
H. Delta Area Network	Yangon - Pathein	H1	8,992	21%	10,076	27%
	Pathein - Hinthada	H2	3,766		2,651	
J. Southern Area Development Corridor	Thanbyuzayat - Hpayarthonesu	J1	2,537	8%	1,482	8%
	Dawai - Thai Border	J2	811		781	
	Dawei - Kawthaung	J3	1,756		1,679	
K. Western North-South Corridor	Yangon - Pyay - Magway	K1	12,810	33%	14,388	42%
	Magway - Mandalay	K2	7,096		5,468	
L. Eastern North - South Corridor	Bilin - Loikaw	L1	3,896	12%	2,550	9%
	Loikaw - Nawnghko	L2	3,247		1,900	

Figure 42: Population and GDP by development corridor (JICA, 2017)

From the figure, it can be concluded that the corridors A, B, and K house most of the Myanmar population, and almost half of the national GDP is situated in these corridors. Yangon is the starting point in all of these three corridors, and Mawlamyine is the starting point of corridor B. Based on this, ports should be located at least at one of these three corridors. This is confirmed by JICA (2014), who state that although deep sea port developments are going on in Kyaukpyu and Dawei (400/500 km away from Yangon) for handling large general cargo/container ships, secondary waterborne transport is needed due to insufficient development of inland transport means and the long distance haul of cargoes to the big market of Yangon from possible new deep sea ports. JICA emphasizes that economic benefit of development of deep sea ports located at a great distance from Yangon is very small.

Another motivation for Yangon and Mawlamyine as potential locations based on the filter 'Distance to market' can be found in Figure 43. This figure shows the freight demand of the ten corridors. Again, the corridors A, B and K (and C, however this is an inland corridor not connected with the sea) show the largest percentages and therefore the largest freight demands. Pathein in corridor H offers large opportunities for using the inland waterway network, which is beneficial because inland water transport is cheap, easily accessible and sustainable. This filter results definitely in the locations Yangon and Mawlamyine, which are also the result in the filter technique in section 6.1.

Development Corridor	Section	Code	2013 Freight demand (million ton-km)	% of traffic demand along corridor	Modal Share (ton-km) in 2013		
					Road	Rail	River
A. Central North-South Corridor	Yangon-Nay Pyi Taw	A1	23.3	27%	93%	7%	0%
	Nay Pyi Taw- Mandalay	A2	15.4	18%	92%	8%	0%
	Mandalay - Myitkyna	A3	2.6	3%	67%	13%	20%
B. East - West Corridor	Yangon - Hpa-An - Myawaddy	B1	10.0	12%	95%	5%	0%
	Mawlamyine - Dawei	B2	0.4	0%	92%	8%	0%
C. Northern Corridor	Mandalay - Muse	C1	11.1	13%	98%	2%	0%
D. Mandalay - Tamu Corridor	Mandalay - Tamu	D1	1.4	2%	75%	7%	18%
E. Second East - West Corridor	Tachilek - Meiktila - Kyaukpyu	E1	2.4	3%	97%	3%	0%
G. East - West Bridging Corridor	Hpasawing - Pyay	G1	0.1	0%	100%	0%	0%
	Loikaw - Magway	G2	1.0	1%	100%	0%	0%
H. Delta Area Network	Yangon - Pathein	H1	1.4	2%	52%	0%	48%
	Pathein - Hinthada	H2	0.2	0%	97%	3%	0%
J. Southern Area Development Corridor	Thanbyuzayat - Hpayarthonesu	J1	0.0	0%	-	-	-
	Dawai - Thai Border	J2	0.0	0%	100%	0%	0%
	Dawei - Kawthaung	J3	0.1	0%	100%	0%	0%
K. Western North-South Corridor	Yangon - Pyay - Magway	K1	8.8	10%	61%	6%	33%
	Magway - Mandalay	K2	2.1	2%	12%	8%	80%
L. Eastern North - South Corridor	Bilin - Loikaw	L1	0.2	0%	100%	0%	0%
	Loikaw - Nawnghko	L2	0.1	0%	97%	3%	0%

Figure 43: Freight demand and modal share by development corridor (JICA, 2017)

Filter 1: World Bank filter

The third filter technique is a first filter based on the Environmental & Social Framework (ESF) from the World Bank. This filter can be used to support Myanmar in satisfying the requirements set by development banks for sustainable development in order to receive loans for projects like deep sea ports. The World Bank sets out this framework through the following set of ten environmental and social standards (ESS):

ESS 1: Assessment and management of environmental and social risks and impacts
ESS 2: Labor and working conditions
ESS 3: Resource efficiency and pollution prevention management
ESS 4: Community health and safety
ESS 5: Land acquisition, restrictions on land use and involuntary resettlements
ESS 6: Biodiversity conservation and sustainable management of living natural resources
ESS 7: Indigenous peoples/sub-Saharan African historically underserved traditional local communities
ESS 8: Cultural heritage
ESS 9: Financial intermediaries
ESS 10: Stakeholder engagement and information disclosure

For application of this filter on the long list of locations, it is chosen to compare the ten ESS's with the selection criteria which are already determined because it turned out that some of the ESS's are similar to the selection criteria used in filter 2. Therefore the ESF is used as a test in order to determine which criteria from the World Bank are missing in filter 2 of the site selection framework, but also to determine which criteria the World Bank is missing in their ESF.

ESS 1: This ESS is in fact similar to a ESIA, which is recommended to carry out in the third phase of the site selection framework (section 5.6).

ESS 2: Labor and working conditions are not represented in the social & political impact of the six main site selection criteria in the framework.

ESS 3: Resource efficiency and pollution prevention management concerns responsible and sustainable operations. This ESS is not directly included in the framework.

ESS 4: Community health and safety concerns the health and well-being of the local people. This ESS is partly included in the site selection criteria as human rights can be evaluated in the MAMCA.

ESS 5: Land acquisition and involuntary resettlements are not included in the framework. Often 'land-grabbing' is used in Myanmar, and involuntary resettlements occur frequently.

ESS 6: This ESS is covered by use of the Ecosystem-tool in the site selection framework. Biodiversity conservation is in fact an Ecosystem Service, as well as managing living natural resources.

ESS 7: It is unknown whether the port sites are home to indigenous people. If so, protecting indigenous people can be included in ESS 4.

ESS 8: Cultural heritage is less important at desolate coastal areas, and is not (yet) included in the framework. This ESS can be combined with the similar site selection sub-criterion 'Protected areas'.

ESS 9: Financial intermediaries facilitate funding between lenders (Worldbank) and borrowers (Myanmar in this case). These financial intermediaries are not included in the framework.

ESS 10: Stakeholder engagement is encouraged in the complete framework and a multi-stakeholder workshop is recommended. This ESS is therefore present in the site selection framework.

Summarizing, ESS 2, 3, 4 and 5 need more emphasis in the site selection framework in order to integrate the Worldbank ESF in the framework. These ESS's concerning labor & working condition, community health & safety, land acquisition and involuntary resettlements, and resource efficiency. Three of these ESS's are related to human rights and social conditions, which may be included in the ESIA. It is therefore recommended to assess whether these ESS's are present in the ESIA which is conducted.

6.3 Filter 2: evaluation process

The process of site identification has been described in section 6.1, however in fact this process of site identification has taken place throughout the whole case study by gathering data and insights from stakeholders. After site identification, the site evaluation and ranking is carried out and described in this section. Evaluation of the four sites is carried out by means of two MCA methods, which are described in section 5.4.1. Two methods are chosen to create higher certainty with respect to the chosen location, and to identify differences between using the two methods. These methods have in common that an impact matrix is required which forms the basis for scoring of sites and evaluation. This impact matrix uses political weights obtained by a multi-stakeholder workshop. First, results of the workshop with respect to the weight parameters will be presented, and afterwards the impact matrix is constructed.

6.3.1 Multi-stakeholder workshop: weight parameters & ecosystem services

A description of activities in the multi-stakeholder workshop is given in section 5.4.3. The relevant results from the workshop for this section (application of the framework) are the weight parameters obtained by the pairwise comparison carried out during the workshop. A complete overview of the workshop results can be found in Appendix I, the results of the weight parameter determination are presented in Table 32.

Table 32: Weight parameters assigned by different stakeholders

	N. Em.	MFSL	MMU	MMU	MMU	IWT	MIP	MIP
Environmental impact	0.15	0.05	0.03	0.08	0.07	0.07	0.05	0.14
Social & Political impact	0.27	0.04	0.07	0.05	**0.50**	**0.33**	0.12	**0.39**
Economic impact	**0.38**	0.25	0.32	0.14	0.09	0.21	**0.39**	0.21
Adaptivity	0.12	0.16	0.09	0.09	0.18	0.12	0.9	0.05
Logistics & construction cost	0.05	**0.34**	0.06	**0.42**	0.13	0.10	0.31	0.10
Feasibility & schedule	0.03	0.16	**0.43**	0.22	0.03	0.17	0.04	0.11

	DMA	DMH	DoF	ACP	MPA	MPA	PEG	Avg.
Environmental impact	0.07	0.11	**0.31**	0.10	0.16	0.06	**0.27**	0.11
Social & Political impact	0.15	0.02	0.19	**0.29**	**0.24**	**0.32**	0.09	0.20
Economic impact	0.14	**0.30**	0.25	0.10	0.18	0.16	0.17	**0.22**
Adaptivity	0.15	0.29	0.08	0.15	0.12	0.05	0.13	0.12
Logistics & construction cost	**0.28**	0.02	0.08	0.18	0.19	0.23	0.22	0.18
Feasibility & schedule	0.21	0.26	0.09	0.18	0.11	0.18	0.12	0.16

The weight parameters are determined for every stakeholder in order to follow the MAMCA approach, and will be used in the impact matrix in the following section. The core of the MAMCA approach is to carry out a MCA for every stakeholder. The first step in the MAMCA approach is definition of the problem and identification of the possible alternatives. The stakeholders are identified in the second step, and the third step comprises choice and definition of the selection criteria which are primarily based on the goals and objectives of the stakeholders. The third step also results in the weight parameters assigned by every stakeholder to the selection criteria. In the fourth step, for each selection criterion one or more indicators are constructed. Lastly, the fifth step comprises of evaluation in the impact matrix, which can be aggregated with different MCA methods. Steps four and five are described in the following sections.

With respect to the valuation of ecosystem services by the stakeholders in the multi-stakeholder workshop, the interactive group session led to similar priorities (1: highest priority, complete results in Appendix I):

1. Fuel/offshore energy 2. Flood protection 3. Erosion/sedimentation regulation

Valuation of the ecosystem services was also tested in an individual questionnaire. These results are similar to the group results:

1. Fuel/offshore energy 2. Erosion/sedimentation regulation 2. Flood protection 3. Seafood

Again, the complete results of the questionnaire can be found in Appendix I. These priorities will be used in the conceptual lay-outs in section 7.

6.3.2 *Impact matrix for MAMCA*

The impact matrix is composed of elements that measure the effect of each considered alternative in relation to each selection criterion in the impact matrix (Vreeker, Nijkamp, & ter Welle, 2001). Before creating and using the impact matrix, it is necessary to define the selection criteria in more detail.

Additional information selection criteria

- The column 'Selection criteria' contains the six main site selection criteria and corresponding sub criteria
- The column 'Type' indicates whether the criteria will be evaluated based on qualitative or quantitative data
- The column 'Indicator' describes the measures for evaluation of the selection criteria
- The column 'Scale' indicates whether a qualitative (+/-) or a quantitative (e.g. km) evaluation scale is used
- The column 'Ref.' shows the source of the data: [1] Google Maps, [2] Atlas Ayeyarwady Delta (IADS consortium, 2017), [3] Myanmar Transport Masterplan (JICA, 2017), [4] (Rao, Ramaswamy, & Thwin, 2005), [5] British Admiralty Charts (2018), [6] Myanmar Logistics Masterplan (JICA, 2017), [7] results from this research

Table 33: Characteristics and evaluation details selection criteria

Selection criteria	**Type**	**Indicator**	**Scale**	**Ref.**
Environmental impact				
- Mangroves	Qualitative	- Distance/removal from mangroves	+++,…,- - -	[2]
- Protected areas	Quantitative	- Distance from area	Kilometer	[3]
- Dredging	Qualitative	- OPEX: sedimentation, coastline stability	+++,…,- - -	[1] [4]
Social & political impact				
- Resettlements	Quantitative	- Relocation of people within 5 km	# villages	[1]
- Labor availability	Quantitative	- Availability within 25 km	# inhabitant	[1]
- Accordance to policy	Qualitative	- Comparison with JICA/MOTC masterplan	+++,…,- - -	[3] [6]
- Tourism impact	Qualitative	- Beaches/nature destroyed, cruise opportunities	+++,…,- - -	
Economic impact				
- Attraction to investors	Qualitative	- Proximity Econ. Cen, SEZ, politics	+++,…,- - -	[1] [7]
- Fishery impact	Qualitative	- Disruption inland/local fishing, distribution of fish, deep water fishing fleet	+++,…,- - -	
- Impact on inequality	Qualitative	- Assess based on GDP/region	+++,…,- - -	[3]
Adaptivity				
- Expansion potential	Qualitative	- Available land, people, industry, connectivity, future (regional) policy	+++,…,- - -	[1] [2] [3] [6]
Logistics/constr. cost				
- Sea, IWT, rail, road, air	Qualitative	- Number and quality of transport modes	+++,…,- - -	[3] [6] [7]
- Shelter	Qualitative	- Possibilities for natural shelter	+++,…,- - -	[1]
- Dredging: depth	Quantitative	- CAPEX: depth (<3 km coast) + material	Meter	[5]
- Distance to Yangon	Quantitative	- Shortest road distance to Yangon	Kilometer	[7]
Feasibility/schedule				
- Timespan	Qualitative	- Phase of actual developments at site	+++,…,- - -	[3] [6]
- Level of complexity	Qualitative	- Risks related to delay and extra costs	+++,…,- - -	

Standardization

Reference is made to section 5.3.1, which shows the activities to be carried out for this decision problem. After setting the criteria, standardization of the criteria is required. As can be seen in Table 33, the criteria are both quantitative and qualitative. In principle each criterion can be measured qualitatively or quantitatively. Some MCA methods are designed to process only quantitative information on criteria (Weighted Summation). In practice, this disadvantage is not very significant because the pluses and minuses used for qualitative assessments are often derived from underlying classes of quantitative data. With a well−chosen method of standardization such as goal standardization this underlying quantitative scale can be used in the weighted summation of these scores (van Herwijnen, Multi-Criteria Analysis Tools, n.d.). This is confirmed by Stratigea & Grammatikogiannis (2012), who state that scores presented in an impact matrix are mutually incomparable due to the different nature of criteria (quantitative and qualitative) and respective measurement units. A certain transformation of scores has to be carried out in order to standardize values. Standardization is carried out based on a maximum value method applied by Stratigea & Grammatikogiannis (Table 34):

Table 34: Standardization of quantitative criteria

	Min. raw score	Score	Max. raw score	Score
Protected areas	0 km	0	150 km	20
Resettlements (<2 km)	0 inhabitants	20	20.000 inhabitants	0
Population (labor) (<25 km)	50.000	0	500.000	20
Hinterland conn.	0 modes	0	4 modes	20
Water depth	8 m	0	14 m	20
Distance Yangon	0	20	700 km	0

In the above table, a minimum and maximum raw score is determined and 0 or 20 points are assigned to the minimum or maximum raw score. The score of raw scores in between the minimum and maximum raw scores are calculated by means of interpolation, so: Standardized 'raw' score = ['raw' score / maximum 'raw' score] * 20. Standardization of the ordinal scale is shown in Table 35:

Table 35: Standardization of qualitative criteria

Ordinal	Score	Meaning	Ordinal	Score	Meaning
---	0	Very high negative impact	+++	20	Very high positive impact
--	4	High negative impact	++	16	High positive impact
-	8	Low negative impact	+	12	Low positive impact

Impact matrix

Criteria:		Weight:	Sites:			
		MPA	A: Pat.	B: Ygn.	C: Mwm.	D: Daw.
Environmental impact		0.06	score	score	score	score
	Mangrove impact		8	12	12	4
	Protected areas		9	8	16	2
	Dredging volume		12	0	16	12
Social & political impact		0.32				
	Resettlements		18	17	19	0
	Labor availability		1	20	3	8
	Accordance to policy		4	20	16	8
	Tourism impact		8	20	12	8
Economic impact		0.16				
	Attraction to investors		12	20	12	8
	Fishery impact		12	8	8	4
	Inequality impact		12	0	20	20
Adaptivity		0.05				
	Expansion potential		12	20	10	13
Logistics & construction cost		0.23				
	IWT, rail, road, air		16	20	16	10
	Available shelter		16	4	12	0
	Water depth		14	7	17	17
	Distance to Yangon		14	20	11	2
Feasibility & schedule		0.18				
	Timespan		8	12	8	20
	Level of complexity		12	8	12	16

Figure 44: Impact matrix being the input for the MAMCA

The impact matrix is presented in Figure 44 and shows the scores of four alternatives (A: Pathein, B: Yangon, C: Mawlamyine, D: Dawei) on the six main criteria with their corresponding sub-criteria. The scores vary between 1 and 20, as explained in the previous section ''standardization''.

Considerations, motivations and references for scoring the alternatives can be found in Appendix J. The scores are assigned by the author of this research. Ranking of qualitative criteria remains a subjective aspect, however it is strived to score the alternatives as objectively as possible.

6.3.3 *Ranking 'Weighted Summation'*

The procedure for carrying out the weighted summation is discussed in section 5.4.1. The results of the weighted summation with weight parameters from Myanmar Port Authority are presented in Figure 45. As can be seen, Yangon scores best (by using the weight parameters of Myanmar Port Authority).

Criteria:		Weight:	Sites:							
		MPA 1	A: Pat.		B: Ygn.		C: Mwm.		D: Daw.	
Environmental impact		**0.06**	score	weighted	score	weighted	score	weighted	score	weighted
	Mangrove impact		*8*	**0.48**	*12*	**0.72**	*12*	**0.72**	*4*	**0.24**
	Protected areas		*9*	**0.54**	*8*	**0.48**	*16*	**0.96**	*2*	**0.12**
	Dredging volume		*12*	**0.72**	*0*	**0**	*16*	**0.96**	*12*	**0.72**
Social & political impact		**0.32**								
	Resettlements		*18*	**5.76**	*17*	**5.44**	*19*	**6.08**	*0*	**0**
	Labor availability		*1*	**0.32**	*20*	**6.4**	*3*	**0.96**	*8*	**2.56**
	Accordance to policy		*4*	**1.28**	*20*	**6.4**	*16*	**5.12**	*8*	**2.56**
	Tourism impact		*8*	**2.56**	*20*	**6.4**	*12*	**3.84**	*8*	**2.56**
Economic impact		**0.16**								
	Attraction to investors		*12*	**1.92**	*20*	**3.2**	*12*	**1.92**	*8*	**1.28**
	Fishery impact		*12*	**1.92**	*8*	**1.28**	*8*	**1.28**	*4*	**0.64**
	Inequality impact		*12*	**1.92**	*0*	**0**	*20*	**3.2**	*20*	**3.2**
Adaptivity		**0.05**								
	Expansion potential		*12*	**0.6**	*20*	**1**	*10*	**0.5**	*13*	**0.65**
Logistics & construction cost		**0.23**								
	IWT, rail, road, air		*16*	**3.68**	*20*	**4.6**	*16*	**3.68**	*10*	**2.3**
	Available shelter		*16*	**3.68**	*4*	**0.92**	*12*	**2.76**	*0*	**0**
	Water depth		*14*	**3.22**	*7*	**1.61**	*17*	**3.91**	*17*	**3.91**
	Distance to Yangon		*14*	**3.22**	*20*	**4.6**	*11*	**2.53**	*2*	**0.46**
Feasibility & schedule		**0.18**								
	Timespan		*8*	**1.44**	*12*	**2.16**	*8*	**1.44**	*20*	**3.6**
	Level of complexity		*12*	**2.16**	*8*	**1.44**	*12*	**2.16**	*16*	**2.88**
		Total:	188	**35.42**	216	**46.65**	220	**42.02**	152	**27.68**

Figure 45: Weighted summation applied on the impact matrix

As stated in section 5.4.1, the MAMCA-approach entails conducting an MCA for every stakeholder. In this research, this can be done by using the weight parameters presented in section 6.3.1. Results of this MAMCA-approach can be found in section 6.3.5. It should be mentioned that the MAMCA-approach is not followed completely. Steps 3 and 5 (described in section 5.4.1) are used from the MAMCA-approach. The aspect of evaluating the impact matrix for every stakeholder is used, together with the assignment of individual weight parameters. However, in the MAMCA-approach from Macharis et al. (2008), the evaluation criteria are the individual goals and objectives from the stakeholders, whereas in this research the evaluation criteria are determined by the researcher and are similar for every stakeholder.

It is also possible to adapt the sub-criterion weight parameters, depending on the stakeholders needs and wishes. For example in Figure 46, ‘fishery impact’ and ‘available shelter’ is given more priority, which causes that Yangon and Mawlamyine are losing points and Pathein is approaching the numbers 1 and 2.

Criteria		Weight	Sites							
		MPA 1	A: Pat.		B: Ygn.		C: Mwm.		D: Daw.	
Environmental impact		0.06	score	weighted	score	weighted	score	weighted	score	weighted
	Mangrove impact	0.06	10	0.6	12	0.72	8	0.48	4	0.24
	Protected areas	0.06	9	0.54	8	0.48	20	1.2	1	0.06
	Dredging volume	0.06	12	0.72	0	0	16	0.96	12	0.72
			31		20		44		17	
Social & political impact		0.32								
	Resettlements	0.32	18	5.76	17	5.44	19	6.08	4	1.28
	Labor availability	0.32	1	0.32	20	6.4	3	0.96	8	2.56
	Accordance to policy	0.32	4	1.28	20	6.4	16	5.12	8	2.56
	Tourism impact	0.32	8	2.56	20	6.4	12	3.84	8	2.56
			31		77		50		28	
Economic impact		0.16								
	Attraction to investors	0.04	12	0.48	20	0.8	12	0.48	8	0.32
	Fishery impact	0.4	12	4.8	8	3.2	8	3.2	4	1.6
	Inequality impact	0.04	12	0.48	0	0	20	0.8	20	0.8
			36		28		40		32	
Adaptivity		0.05								
	Expansion potential	0.05	12	0.6	20	1	10	0.5	13	0.65
Logistics & construction cost		0.23								
	IWT, rail, road, air	0.13	16	2.08	20	2.6	16	2.08	10	1.3
	Available shelter	0.5	16	8	4	2	12	6	0	0
	Water depth	0.16	14	2.24	7	1.12	17	2.72	17	2.72
	Distance to Yangon	0.13	14	1.82	20	2.6	11	1.43	2	0.26
			60		51		56		29	
Feasibility & schedule		0.18								
	Timespan	0.18	8	1.44	12	2.16	8	1.44	20	3.6
	Level of complexity	0.18	12	2.16	8	1.44	12	2.16	16	2.88
			20		20		20		36	
Total			348	35.88	392	42.76	410	39.45	261	24.11

Figure 46: Weighted summation applied with adapted sub-criterion weight parameters

Considerations, motivations and references for scoring the alternatives can be found in Appendix J.

Sensitivity analysis

Table 36 and Table 37 show the results of a sensitivity analysis (+20% and -20%) carried out for the weight parameter set of the Myanmar Port Authority. This stakeholder is chosen because it represents the social & political cluster which is considered to be the leading cluster. Within this leading cluster, Myanmar Port Authority is the highest decision-making authority.

Table 36: Sensitivity analysis +20%

	Default	+ 20%	Pathein	Yangon	Mawlam.	Dawei
Environmental impact	0.06	0.07	35.40	46.08	41.96	27.62
Social & political	0.32	0.38	35.51	49.68	43.12	27.48
Economic impact	0.16	0.19	35.39	46.01	41.96	27.75
Adaptivity	0.05	0.06	34.63	45.57	41.06	27.28
Logistics/constr. Cost	0.23	0.28	37.05	47.55	42.94	28.08
Feasibility/schedule	0.18	0.22	34.35	45.38	40.8	27.98
Default results	-	-	35.42	46.65	42.02	27.68

Table 37: Sensitivity analysis -20%

	Default	- 20%	Pathein	Yangon	Mawlam.	Dawei
Environmental impact	0.06	0.05	35.44	47.22	42.08	27.74
Social & political	0.32	0.26	35.33	43.62	40.92	27.88
Economic impact	0.16	0.13	35.37	47.29	41.98	27.38
Adaptivity	0.05	0.04	35.61	47.22	42.42	27.79
Logistics/constr. Cost	0.23	0.18	33.61	45.75	40.62	27.64
Feasibility/schedule	0.18	0.14	36.01	47.61	42.78	27.22
Default results	-	-	35.42	46.65	42.02	27.68

The results show little changes in the scores. The ranking is not changed in any of the situations and therefore no additional sensitivity analysis are carried out for the other clusters. Besides, the MAMCA-approach provides similar results compared to a sensitivity analysis because the MAMCA-approach evaluates the impact matrix with 16 different weight parameter sets.

6.3.4 *Ranking 'ELECTRE-I method'*

The ELECTRE-I method uses the impact matrix presented in Figure 44 as basis for ranking the alternatives. As explained in section 5.4.1, the following steps will be taken for evaluation by means of ELECTRE-I:

1. Construction of a concordance matrix which indicates for the different alternatives whether they score better than or equal than to other alternatives. For these alternatives, the weights are summed up.
2. Construction of the net-concordance matrix by summing up every row and subtract every column.

Table 38: Concordance matrix

Alternative	A: Pathein	B: Yangon	C: Mawlamyine	D: Dawei
A: Pathein	-	0.68	0.46	0.66
B: Yangon	0.55	-	0.55	0.66
C: Mawlamyine	0.72	0.63	-	0.82
D: Dawei	0.34	0.34	0.23	-

Example: Pathein scores better or equal than Yangon on environmental impact, economic impact, adaptivity, logistics & construction cost and feasibility/schedule, which results in a concordance value of 0.06 + 0.16 + 0.05 + 0.23 + 0.18 = 0.68. This means that Pathein scores as well or better than Yangon in one or more criteria, and the weights of these criteria summed up total 0.68.

Table 39: Net concordance dominance matrix

	A: Pathein	B: Yangon	C: Mawlamyine	D: Dawei
Net concordance	0.19	0.11	0.93	-1.23

The ELECTRE-I method values Mawlamyine number one, while the weighted summation method valued Yangon number one. This indicates that evaluation methods should be handled with great care.

6.3.5 *Scenario-based ranking by clustering*

During the multi-stakeholder workshop it became clear that weight parameters and priorities differ substantially between stakeholders. This can be dealt with in two different ways:

1. As mentioned in section 5.4.1, the MAMCA-approach suggests carrying out separate MCA's for every stakeholder and its set of weight parameters. This is comparable with a sensitivity analysis.
2. Within the group of sixteen sets of weight parameters, similarities can be found, and it is possible to conduct four MCA's, based on four 'scenario's or 'clusters' of stakeholders who value for example the environmental impact as the highest criterion. These clusters can be coupled to policy objectives, as for example the environmental impact of future ports is considered to be very important. The four scenario's or clusters are presented in Table 40. It should be noted that the differences between the other five weight parameters within a cluster should not be too large.

Table 40: Scenario's or clusters based on similar preferences

	Environmental cl.			*Social & political cluster*						
Crit.	**DoF**	**PEG**		**DMA**	**MIP**	**ACP**	**MPA**	**MMU**	**IWT**	**MPA**
1. Environm.	0.31	0.27		0.07	0.14	0.1	0.06	0.07	0.07	0.16
2. Social	0.19	0.09		0.33	0.39	0.29	0.32	0.5	0.33	0.24
3. Economic	0.25	0.17		0.21	0.21	0.1	0.16	0.09	0.21	0.18
4. Adaptivity	0.08	0.13		0.12	0.05	0.15	0.05	0.18	0.12	0.12
5. Log./Con.	0.08	0.22		0.1	0.1	0.18	0.23	0.13	0.1	0.19
6. Feasibility	0.09	0.12		0.17	0.11	0.18	0.18	0.03	0.17	0.11

	Economic cluster					*Costs cluster*		
Crit.	**N. Emb.**	**MIP**	**DMH**	**MMU**		**MFSL**	**MMU**	**DMA**
1. Environmental	0.15	0.05	0.11	0.03		0.05	0.08	0.07
2. Social	0.27	0.12	0.02	0.07		0.04	0.05	0.15
3. Economic	0.38	0.39	0.3	0.32		0.25	0.14	0.14
4. Adaptivity	0.12	0.09	0.29	0.09		0.16	0.09	0.15
5. Logis./constr.	0.05	0.31	0.02	0.06		0.34	0.42	0.28
6. Feasibility	0.03	0.04	0.26	0.43		0.16	0.22	0.21

The weight parameters from these clusters will be the input for the MAMCA, a MCA for every separate stakeholder. The rankings are presented in Table 41, and obtained by means of weighted summation.

Table 41: MAMCA outcomes per stakeholder

	Environmental cluster			*Social & political cluster*						
	DoF	**PEG**		**DMA 1**	**MIP 1**	**ACP**	**MPA 1**	**MMU 1**	**IWT**	**MPA 2**
1.	Maw **40**	Maw **39**		Ygn **44**	Ygn **47**	Ygn **43**	Ygn **47**	Ygn **53**	Ygn **44**	Ygn **41**
2.	Ygn **35**	Pat **34**		Maw **38**	Maw **42**	Maw **38**	Maw **42**	Maw **41**	Maw **38**	Maw **40**
3.	Pat **31**	Ygn **33**		Pat **31**	Pat **33**	Pat **32**	Pat **35**	Pat **31**	Pat **31**	Pat **34**
4.	Daw **24**	Daw **25**		Daw **26**	Daw **26**	Daw **26**	Daw **28**	Daw **23**	Daw **26**	Daw **25**

	Economic cluster					*Costs cluster*				
	N. Emb	**MIP 2**	**DMH**	**MMU 2**		**MFSL**	**MMU 3**	**DMA 2**		**Total**
1.	Ygn **40**	Maw **43**	Maw **27**	Daw **31**		Maw **38**	Maw **40**	Ygn **38**		Ygn **39**
2.	Maw **40**	Pat **40**	Daw **24**	Maw **30**		Pat **37**	Pat **40**	Maw **38**		Maw **38**
3.	Pat **31**	Ygn **40**	Ygn **24**	Ygn **28**		Ygn **35**	Ygn **37**	Pat **35**		Pat **33**
4.	Daw **25**	Daw **28**	Pat **24**	Pat **28**		Daw **28**	Daw **28**	Daw **27**		Daw **26**

It can be seen that Mawlamyine wins in the environmental cluster and Yangon wins the social & political cluster. Yangon and Mawlamyine score almost equal in the economic cluster and the costs cluster. When averaging scores, Yangon and Mawlamyine lead. According to Macharis et al. (2008), when the government is one of the stakeholders, which is usually the case in the evaluation of transport projects, one could say that this government stakeholder represents the society's point of view and therefore should be the one to follow. Analysis of the points of view of the other stakeholders, like users, local population, manufacturers, and so on, will then show if a certain measure will possibly be adopted or rejected by these groups.

6.3.6 *Ecosystem services tool*

Within this research, the main contribution to sustainable port development, is the ability of a port location to have the least negative impact on the ecosystem services as possible on the one hand, and maximize opportunities regarding these ecosystem services on the other hand. This ecosystem services evaluation is not included in the MCA, but an ecosystem-interrelations tool is used, as motivated in section 5.4.4. After scoring the MCA, it can be concluded that Mawlamyine and Yangon are ranked highest. The ecosystem-tool will be applied on these two locations, in order to obtain the location with the least negative impact on the ecosystem. De Boer (2016) applied the tool on three sub-regions, in which marinas can be planned:

1. **Coral beaches**: feature coral reefs, shallow lagoons, carbonate sand beaches
2. **River mouth**: presence of river discharges, non-presence of corals, deep water channels, bare bottoms
3. **Mangrove region**: possible near river discharge, shallow water, deep water, combination

The three abovementioned sub-regions provide the same ecosystem services, however in different degrees compared to each other. This degree of provision is assumed to be the same for the Myanmar-case in this research as for the Mauritius-case in the research of G. de Boer (2016), however only the river mouth sub-region and the mangrove sub-region are used because coral beaches hardly occur along Myanmar's coastline. Figure 47 shows the presence of ecosystem services for the river mouth sub-region and the mangrove sub-region, and shows the importance of the ecosystem services for deep sea ports based on G. de Boer and stakeholder interests derived during the workshop (Appendix I).

Horizontal: Ecosystem services (UNEP, 2011)	Provisioning: 1. (Sea)food provision	Provisioning: 2. Fresh water storage and provision	Provisioning: 3. Offshore energy	Regulating & supporting: 4. Flood protection	Regulating & supporting: 5. Erosion and accretion regulation	Regulating & supporting: 6. Wildlife habitat and biodiversity	Regulating & supporting: 7. Climate regulation	Cultural: 8. Recreation and (eco-tourism)	Cultural: 9. Aestethic and visual aspects
River mouth sub-region	2	0	2	3	3	2	3	1	1
Mangrove sub-region	4	0	0	5	5	5	5	3	3
Deep sea port importance	3	0	5	5	5	3	1	2	2

Figure 47: Ecosystem services presence and importance for deep sea port

- The mangrove sub-region scores 5 (maximum) provisioning points on flood protection and erosion/accretion regulation because mangroves damp wave impact and strong currents. Furthermore, mangrove forests are capable of trapping sediments which strengthen a coastline.
- The river mouth sub-region scores 1 provisioning point on recreation and eco-tourism and aesthetic/visual aspects because river mouth areas are often characterized by strong currents, dynamic coastal conditions and relatively less vegetation, causing them to be less attractive to recreating people.
- The ecosystem service '(sea)food provision' scores 3 points, because (sea)food provision can attract fisheries which can use the port, however fisheries can also hinder the maritime shipping of a port.

			River mouth	Mangroves
1.	Deep seaport	Structural elementes: quay walls, breakwaters, jetties	5	4
2.	Deep seaport	CAPEX dredging of approach channel & basins	5	3
3.	Deep seaport	OPEX dredging of approach channel & basins	5	2
4.	Deep seaport	Bottom structures: jetty anchoring, navigation marks	3	3
5.	Deep seaport	Construction & maintenance	5	5
5.	Operations	Vessel presence: mooring, waste, engine nuisance	3	3
6.	Operations	Onshore activities: loading, unloading, industries	3	3
7.	Operations	Marine activities: fishing, tugboats, sailing	3	4

Figure 48: Presence and importance of elements per sub-region

Besides different degrees of provision of ecosystem services, distinction should be made between presence and importance of deep sea port elements for the two different sub-regions. This is depicted in Figure 48. For example, shallow water areas near the river mouth are more likely to require extra structural elements. OPEX dredging is a deep sea port element which is probably substantially more important in areas with large sediment flows than in mangrove areas.

In Figure 49, the ecosystem-tool is presented for the sub-region ‘river mouth’, depicted by Yangon area as potential deep sea port site, and for the sub-region Mangrove region depicted by Mawlamyine area. Evaluation by means of the ecosystem-tool follows the same procedure as G. de Boer: the tool shows interrelations between the deep sea port element and the ecosystem services. The interrelation signifies the mutual impact and is rated from very negative (- -) to very positive (+ +). An interrelation that has both negative and positive effects is depicted by (±) and the absence of an interrelation is depicted by 0. Considerations, motivations and references for scoring the ecosystem interrelations can be found in Appendix J.

				Provisioning			Regulating & supporting				Cultural	
		Horizontal: Ecosystem services (UNEP, 2011) Vertical: Deep sea port elements		1. Seafood/fisheries	2. Fresh water storage and provision	3. Offshore energy	4. Flood protection	5. Erosion and accretion regulation	6. Wildlife habitat and biodiversity	7. Climate regulation	8. Recreation and (eco-tourism)	9. Aestethic and visual aspects
				2	0	2	3	3	2	3	1	1
1.	Deep sea port	Structural elements: quay walls, breakwaters, jetties	5	++	0	+	±	++	+	-	++	±
2.	Deep sea port	CAPEX dredging of approach channel & basins	5	0	0	0	+	+	-	-	0	0
3.	Deep sea port	OPEX dredging of approach channel & basins	5	-	0	0	++	++	--	--	0	0
4.	Deep sea port	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	±	0	0	0
5.	Deep sea port	Construction & maintenance	5	0	0	+	0	+	-	-	0	-
6.	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	0	--	-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8.	Operations	Marine activities: fishing, tugboats, sailing	3	-	0	0	0	0	0	0	+	+

Figure 49: Ecosystem interrelations tool for sub-region 'river mouth'

Guidance relating to application of the ecosystem-tool on the sub-region river mouth:

- The sub-region ‘river mouth’ is characterized by: large sediment flows from river discharges, small water depths and absence of seagrass meadows, coral reefs and mangroves.
- The most important aspect of this sub-region is the discharging of water and sediment into the sub-region, which interrelates strongly with flood protection and erosion and accretion regulation. Sediment transport can increase the flood protection of the natural system, and fills erosion gaps.
- Due to the large amounts of sediment, heavy dredging activities are expected. A positive score for CAPEX/OPEX dredging is given regarding the ecosystem service ‘flood protection’, Dredging provides large depths to the river area which increases the discharge capacity. Dredged material can be used to fill erosion gaps. A small disadvantage is the possible removal of natural sandbanks which function as flood protection.
- Positive scores are given for CAPEX/OPEX dredging regarding the ecosystem service ‘erosion and accretion regulation’, because dredging material can be used at places where erosion occurs.
- Neutral scores are given to the interrelation ‘structural elements’ with the ecosystem service ‘flood protection’ and ‘erosion and accretion regulation’, because large fixed elements strongly affect current flows and sedimentation, which affects the natural equilibrium. However villages behind a port may be protected by the structural elements.

In Figure 50, the ecosystem-tool is presented for the sub-region ‘mangroves’, depicted by Kalegauk Island as potential deep sea port site. Considerations, motivations and references for scoring the ecosystem interrelations can be found in Appendix J.

				1.	2.	3.	4.	5.	6.	7.	8.	9.
				Provisioning			Regulating & supporting				Cultural	
		Horizontal: Ecosystem services (UNEP, 2011) Vertical: Deep sea port elements		Seafood/fisheries	Fresh water storage and provision	Offshore energy	Flood protection	Erosion and accretion regulation	Wildlife habitat and biodiversity	Climate regulation	Recreation and (eco-tourism)	Aestethic and visual aspects
				4	0	0	5	5	5	5	3	3
1.	Deep seaport	Structural elements: quay walls, breakwaters, jetties	4	++	0	+	-	-	+	-	++	±
2.	Deep seaport	CAPEX dredging of approach channel & basins	3	0	0	0	--	--	--	-	+	0
3.	Deep seaport	OPEX dredging of approach channel & basins	2	-	0	0	-	±	--	--	+	0
4.	Deep seaport	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	±	0	0	0
5.	Deep seaport	Construction & maintenance	5	0	0	+	-	0	+	-	0	-
6	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	-	--	-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8	Operations	Marine activities: fishing, tugboats, sailing	4	-	0	0	0	0	0	-	+	+

Figure 50: Ecosystem interrelations tool for sub-region 'mangroves'

Guidance relating to application of the ecosystem-tool on the sub-region mangroves:

- The sub-region ‘mangroves’ provides stronger degrees of ecosystem service provision than the sub-region ‘river mouth’. Mangroves serve in flood protection, erosion and accretion regulation, air quality regulation, and are home to many species and therefore facilitate food provision.
- Mangroves (and to a lesser extent, seagrasses) are sensitive to change of their environment. Conditions like calm waters, salinity levels and water quality are important for its survival (de Boer G. G., 2016). Therefore, dredging works close to mangrove area, affecting their sediment supply and wave patterns, may result in a decrease of the mangroves state.
- Dredging activities near mangroves can cause deterioration of the mangroves and negatively influence the habitats of species living in the mangroves, therefore negative scores are appointed.
- Bottom structures on the one hand can damage bottom habitats, but these structures can also serve as habitat area and increased vegetation area. Therefore a plus/minus score is given in relation with the ecosystem service ‘wildlife habitat and biodiversity’.

It can be concluded that the sub-region ‘’mangroves’’ is a more sensitive area compared to the sub-region ‘’river mouth’’. In view of this, river mouth areas in Myanmar are more suitable locations than mangrove areas. The next section will elaborate upon measures which can minimize the negative impacts and maximize the positive impacts which are indicated in the Ecosystem tool.

6.4 Framework manual and additional information

This section discusses the various phases in the site selection framework in detail.

Phase 1 ''Project initiation'' & phase 2 ''Requirements study''

During the case study it became clear that the drivers and financing possibilities for the proposed deep sea port should be known as early in the process as possible. The type of driver is crucial for site selection as a transshipment port requires proximity to main shipping routes while gateway ports require proximity to the main hinterland the port is going to serve, and extensive hinterland connectivity. Besides the drivers for port development, options for financing should be known in early stages. Financing was considered to be the biggest challenge by stakeholders during consultations and during the multi-stakeholder workshop, as always for new port projects. A large part of the investments come from development banks and private investors, and early mapping (and preferably contracting) of investors avoids waste of money and labor spent on (pre)-feasibility studies.

Section 2.3 discussed several interpretations of sustainable port development. Throughout the last decades, many definitions and working practices are developed for assisting in sustainable port development. This research and the site selection problem in this research approaches sustainable port development by thinking and designing from the opportunities provided by the ecosystem: Ecosystem-Based Management. Combined with early stakeholder involvement, a framework and interpretation of sustainable port development was made. Especially in countries like Myanmar, where sustainable development is a new and relatively unexplored subject, clear definitions and goals of sustainable development are needed, together with support from all stakeholders to strive for sustainable port development. Defining sustainable development, identifying needs and values, and create support can be accomplished in a kick-off workshop for relevant stakeholders.

Concerning the requirements study in phase 2, a concise study is recommended based on the planning process from Thoresen (section 3.2) and a feasibility study from Arcadis (Arcadis, 2013). A three-step process is suggested in which firstly the port model and port type is determined, subsequently the trading situation is mapped and lastly the technical, morphological and hydrodynamic aspects are determined. For Myanmar, setting up trade forecasts can be complex due to lack of historical data, an instable political situation and GDP fluctuations in the order of 5-10%. Therefore it is recommended to the Ministry of Transport and Communications to use several methods e.g. forecasting by examining the GDP trends, comparison with surrounding countries and extrapolation of trade trends of the key commodities. The output from various methods should be compared in order to obtain more reliable outputs, and a wide range between average, low and high cases should be used in sensitivity analyses.

Phase 3 ''Site identification, evaluation & ranking''

The key phase of the framework and the site selection process is the actual selecting of the sites. This can be subdivided into identification of possible sites into a long list, evaluation of the long list by means of a filter technique, and lastly the ranking of sites based on stakeholder preferences or predefined economic or political scenario's.

Phase 3 starts with determination of the filter technique. A 2-step filter process is suggested in which a long list is evaluated in a first filter to end up with a short list. The short list is subsequently evaluated in the second step by using an evaluation method such as a Multi-Criteria Analysis. For the first filter, four different filter techniques are suggested in section 6.2. These filters are based on: four criteria (available land, connectivity, water depth, natural shelter), the distance to the market of the port, sustainability considerations, or a combination of these filters in a 3-step process. After this first filter, a decision should be made whether an extensive application of the evaluation in the second step on the short list is needed (Go/No-Go decision). This decision depends on the number of remaining sites in the short list and the degree to which alternatives differ on the most important criteria (decision turning point). If the shortlist is long, perhaps another filter should be applied because applying MCA's or CBA' on a large number of sites can be a costly operation. However, if 2 similar sites remain in the short list and it can easily be concluded that 1 is twice as expensive as the other one without significant advantages, an evaluation of these two sites in a MCA or CBA is not required. Lastly, after the first filter sites may be rejected if so-called showstoppers (section 6.1) are detected. Showstoppers have such significant disadvantages for a specific site that it is not feasible to proceed with that site. Examples of showstoppers are the political situation in an area, limited budgets and rejection of a location due to results of an Environmental and Social Impact Assessment (ESIA). It is common practice to consider key ESIA factors in creating a long list and develop these criteria until the formal ESIA is submitted. It is strongly recommended to conduct an ESIA before site selection so the results of this ESIA can be used as input for the site selection process.

If it is decided to proceed with the evaluation step in the 2-step process of phase 3, four tasks (depicted in the rectangle in the framework) need attention. Firstly the evaluation method needs to be chosen. Based on literature and desk study in sections 5.3 and 5.4.1, four evaluation methods are suggested: MCA, MAMCA, SWOT, CBA. The choice for a method mainly depends on the type of data (qualitative, quantitative, monetary) and the decision-maker. This research used a MAMCA-approach, which asks for determination of selection criteria in task 2. These selection criteria together with the sub-criteria can be used by the Ministry of Transport and Communications, however a new set of selection criteria can also be determined. To reflect the needs and values of different stakeholders in the selection process, weight parameters can be assigned to the selection criteria. One way to perform this, which turned out to be useful for this research as well, is by organizing a multi-stakeholder workshop. A workshop with participants from both the public as well as the private sector offers opportunities for determining priorities of selection criteria. The pairwise comparison method assists in determining the priorities and delivers transparent results and traceability in decision-making.

The fourth task concerns the Ecosystem-Based approach in the site selection process. Sections 0 and 6.3.6 describe this approach by means of the Ecosystem-tool which is able to indicate positive and negative interrelations between (structural) elements of a (new) port and the ecosystem services in a specific area. Based on this tool, it can be concluded that a river mouth sub-region offers more positive interrelations and less negative interrelations compared to a mangrove area, mostly originating from dredging activities. Results from this Ecosystem-tool can be integrated in the selection process in order to score sites on their results from the Ecosystem-tool as well. However, in this research the Ecosystem-tool is mainly used as a test for the conceptual design. Focal areas (strong positive and negative interrelations) are used to align the Ecosystem-Based design principles with the specific sub-region.

After the evaluation step in the 2-step process, a ranking of sites is obtained. Scenario-based ranking turned out to be a good option for ranking the sites, due to the possibility of selecting four scenario's based on so-called 'clusters' of like-minded stakeholders (section 6.3.5). The first cluster is based on environmentally oriented stakeholders which indicates the scenario of political objectives that tend to move towards emphasis on environment. The other three clusters and corresponding scenarios are the social and political cluster, the economical cluster and the costs cluster (aiming for the lowest price). The social and political cluster is chosen to obtain the ranking in this research, because this cluster represents the society's point of view in the evaluation of transport projects and is therefore the one to follow. Following this scenario, Yangon is the optimum site, followed by Mawlamyine, Pathein and Dawei.

Phase 4 ''Lay-out''

Phase 4 of the framework presented in section 7 concerns development of lay-out alternatives in which sustainability measures are included. This phase is added in a later stage of this research in order to present sustainable design principles in a concrete and visual way which can be used by the Ministry of Transport in Myanmar to further develop ideas, and to compare different site lay-outs. For the lay-outs in section 7.2, four major considerations are discussed and included in the framework and lay-outs: zoning & phased development, hinterland connections, marine infrastructure, and breakwater considerations. These four aspects turned out to be sufficient in order to apply sustainable design principles and to provide the Ministry of Transport with visual representations of the lay-outs.

7 ALTERNATIVE LAY-OUTS

A common next step in port development, after site selection, is development of conceptual lay-outs in order to obtain visualizations of the specific location. At the beginning, setting up a conceptual lay-out was not a research objective however it became clear that designing a lay-out strongly contributes to insights regarding applications of sustainable port development and ecosystem services. Furthermore a conceptual lay-out can be very attractive for the stakeholders in Myanmar because opportunities and sustainable design principles are shown in a concrete and visual way which they can use to further develop ideas and compare sites, rather than providing the stakeholders with a ranking of possible sites.

To determine the most important aspects of this conceptual lay-out, and to make sure the lay-out will not become too detailed, use is made of the expert validations from section 5.5. The conceptual lay-out will elaborate on zoning and phased development opportunities, hinterland connections, the most important marine infrastructure, port protection, and sustainable design principles from ecosystem-based management. For every aspect, considerations are described which help Myanmar in deciding between design options. The trade and traffic forecast together with basic functional requirements (section 3.2) give the requirements of the port in terms of type, size and number of vessels to be calling the port. Using basic information about the governing wind, waves and water levels, a first lay-out of the wet infrastructure can be made.

The following remarks should be kept in mind when reading section 7.1:

- The considerations and design principles can be used for every site.
- In some situations, the considerations are made location-specific. The location-specific considerations are only relevant for Yangon and Mawlamyine.
- The type of port is not fixed yet. Some considerations deal with a traditionally located port along the shoreline and some considerations deal with offshore ports.
- To guide this section towards sustainability, it is strived to formulate the considerations and design principles in such a way they minimize negative impacts and maximize positive impacts.

After the general considerations presented in section 7.1, section 7.2 shows four options for port development in order to show applications of the eleven sustainable design principles which are described in section 7.1.1.

7.1 Major considerations

As mentioned in Ligteringen (2017), the lay-out of a port is to a large extent determined by its wet lay-out. The wet lay-out includes orientation and dimensions of the approach channel, the maneuvering areas within breakwaters (if required), turning circle, and the port basins for mooring at the berths. These aspects are of great importance firstly because they constitute a major part of the overall investment, and secondly because they are difficult to modify once the port has been built. Another important aspect is the sediment transport, and especially the alongshore sediment transport. The effect of the port lay-out on the natural sediment processes, and hence on the coast should be known. Siltation in the port and approach channel should be minimized by the lay-out.

7.1.1 Sustainable and EBM design principles

Sustainable port development can be interpreted in many ways. In this research, sustainable port development is aimed at minimizing negative impacts on the ecosystem on the one hand, and maximizing value for both the ecosystem and stakeholders on the other hand, based on the values and needs of these stakeholders. This is called 'co-creation of values' and will be leading in creating a sustainable conceptual lay-out. This approach is also called 'mutual gains'. This means for a traditional port development project that it needs to upscale to a broader scope to include stakeholder values related to the labor market, living environment and accessibility. For this section, it is stated that sustainable design of ports can be approached at four different levels (W. de Boer, personal communication, 12-4-2018). This is an interpretation of the author based on interviews with W. de Boer. After this interpretation, a brief summary of the original work of de Boer et al. (2018) will be presented, which was published by the time of finishing this research on site selection. The four levels are as follows:

1. **Go/No-Go decision:** a comprehensive requirements study and analysis of existing ports should be carried out in order to determine whether a new port or a port development is really necessary. Countries often want bigger ports because they see neighboring countries doing the same. However, by improving collaboration between countries, they might use neighboring ports for transshipment of their own goods.
2. **Brownfield/greenfield:** at brownfield locations an intervention in the ecosystem has already been made. This intervention can often be seen as negative impact or damage, and therefore development at brownfield locations causes potentially less incremental negative impact than a development on a greenfield location.
3. **Type of port:** traditional port development is an alongshore development with breakwaters to ensure a mild climate for entering ships, but also to prevent the approach channel and port basins from filling with alongshore sediment. More sustainable options could be open ports (mostly riverine ports or natural ports), ports on an offshore island, or offshore jetties. Open ports make use of mild wave climates to avoid or minimize the construction of breakwaters and minimize coastal impact (examples in section 7.1.5). Offshore ports are located on natural or artificial offshore islands in relatively stable morphological areas which minimizes coastal impact and might cause milder climates near the coastline. Offshore jetties provide one specialized terminal for vessels offshore. Figure 53, Figure 54 and Figure 55 show some examples.
4. **Ecosystem-based and sustainable design principles:** this final level concerns sustainable design principles based on the negative and positive interrelations derived in section 6.3.6. Positive interrelations will be applied in the design, and negative interrelations avoided or mitigated. All design principles below can be linked to the Ecosystem Services as mentioned in Figure 47 in section 6.3.6. The numbers between brackets behind each sustainable design principle indicate the corresponding Ecosystem Service from Figure 47. Examples of these design principles are:

- **Reuse of dredged material [4,5,6]**: reuse of dredged material as construction material, to prevent erosion, or to create wetlands for biodiversity is useful and avoids damage via disposal to valuable seagrass meadows (Deltares, 2015).
- **Current deflecting wall [5,7]**: current deflecting walls reduce horizontal eddies in the port entrance, and deflect the near bed sediment transport along the shoreline (PIANC, 2008).
- **Designing structures on piles [2,5,6]**: designing on piles instead of fully concrete structures offers opportunities to avoid still standing water, increasing the quality, and causes less deviation of water flows.
- **Fishery facilities [1]**: small areas in the proximity of a port development can be designated as fishery areas. However, these locations should be chosen carefully because fishery boats and fishing nets often cause hindrance in the proximity of shipping routes. Besides, small jetties can be provided for fishery boats to stimulate the fisheries. These jetties should not be placed inside the port to avoid hindrance.
- **Mangrove, seagrass and corals preservation [1,4,5,6,7,8,9]**: mangroves hold sediment, cycle nutrients, clean air and offer habitats to species which are important for biodiversity and ecosystem resilience (de

Boer G. G., 2016). Coral reefs, seagrass meadows and mangroves, either alone or in combination, offer natural and effective ways to prevent coastal erosion, as well as to enhance ecosystem services such as water filtration and opportunities for fisheries and recreation (de Vriend & van Koningsveld, 2012).

- **Eco-engineering [1,4,5,6]**: added value could be obtained by creating favorable circumstances for new habitats or restoration of disturbed areas, such as artificial oyster reefs in breakwaters and reusing dredged material (Deltares, 2015). Existing structures may not have been designed to provide habitats for marine species, but can be altered during maintenance or upgrading, e.g. by retrofitting special tiles that provide a variety of habitats (de Vriend & van Koningsveld, 2012)
- **Protecting or creating tidal flats [4,5]**: tidal flats are not only valuable, diverse and productive habitats, but also dissipate wave energy, and help to protect the hinterland from flooding. Dredged material from maintenance dredging can be used to nourish tidal flats, or oyster reefs on top of tidal flats can build up solid reef structures which are able to withstand winds and waves (de Vriend & van Koningsveld, 2012).
- **Possibilities for a 'plastic trap':** a clean-up system can be developed if waste accumulates somewhere naturally. The port can actively contribute to the cleaning of the marine near-shore pollution (Vrolijk, 2015).
- **Seabed landscaping technique [1,6]:** traditionally dredgers would extract sand and leave the floor of the pit relatively flat. Landscaped areas similar to natural bedforms and sand waves with stable sand ridges hypothetically improve recolonization of dredged areas, speeding up the recovery of the biodiversity and reducing the impact of dredging activity (de Vriend & van Koningsveld, 2012)
- **Environmental compensation [1,6]:** to compensate for lost parts of habitat, protected seabed areas can be realized. At these locations, fishing vessels that stir up the seabed are prohibited (Port of Rotterdam, 2008). Another way of nature compensation is creating new dune areas. These compensation measures ensure that the existing protected nature will not be worse off due to port construction.
- **Deep sand extraction pits:** extraction of sand from the seabed will result in disappearance of local seabed organisms. Negative environmental effects can be limited by using deep sand extraction pits. Extracting downward instead of sideward limits the total disturbed area (Port of Rotterdam, 2008).
- **Cruise/ferry activities:** although these modes of transport are not highly sustainable, they provide large opportunities for attracting (eco)-tourism, which boosts local economies.

For most of the design principles mentioned above, practicality and commerciality has to be investigated in more detail. However, they provide good guidance in sustainable port development and the ways of thinking which are related to sustainable port development.

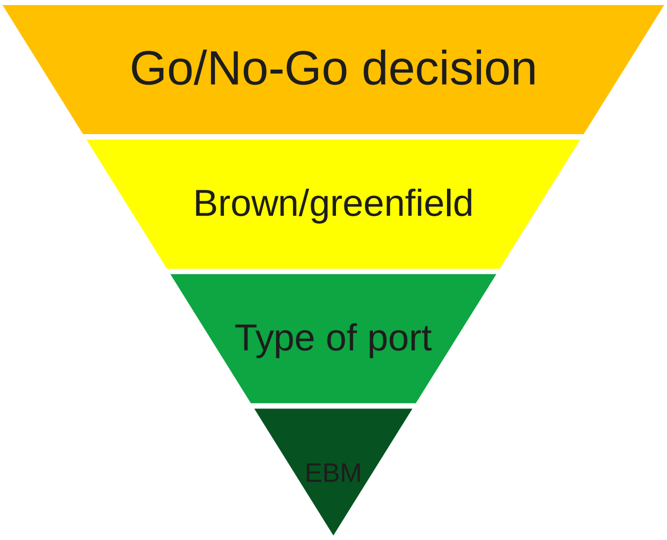


Figure 51: Pyramid of sustainable port development (source: author)

The different levels of sustainable development are depicted in the inverse pyramid of sustainable design. The considerations at level three and four will be used for the conceptual lay-out. In the following sections, considerations with regard to dredging, hinterland connections, the marine infrastructure, breakwater protection and zoning will be discussed. With a focus on sustainable measures and design principles. These considerations are mainly related to the third level 'type of port'. Concerning level four, the EBM-level, the ecosystem-tool evaluated in section 6.3.6 is leading. Critical results (strong negative or strong positive impact) from the ecosystem-tool will be leading in order to minimize negative impacts on ecosystem services and maximize positive impacts.

About the pyramid: the top level is the level with the largest influence on the level of sustainability. Because a no-go decision is in fact the most sustainable decision. However, it is more common that this decision is a go decision, and therefore the overall sustainable contribution is rather low. The bottom 'EBM' level has a smaller influence (eco-engineering vs. absence of a port development), but these design principles are almost always applicable and therefore always contribute to sustainability of a port.

The above hierarchy including the ecosystem-based design principles is the interpretation of the author on the work of de Boer et al. (2018). Level 3 'Type of port' and level 4 'EBM' will be leading in section 7.2. Below a short summary of the original work of de Boer et al. will be provided, which is similar to the interpretation of the author. De Boer et al. present a framework for the explicit inclusion of ecosystem-based alternatives in the early planning and design stages of seaport developments. As stated in section 2.4 of this research, it is stated that early acknowledgement of the need and embedment of sustainable measures avoids situations in which sustainability is only considered during the preliminary or final design phase. In later design phases, sustainability can only be achieved on minor scales, while selecting a port site can have major influences on sustainability of the port under consideration. This is acknowledged by de Boer et al. (2018), who developed their framework (presented in Figure 52) to aim for a shift of focus from offsetting environmental impacts afterwards to avoidance and reduction of environmental impacts as integral part of seaport planning and design.

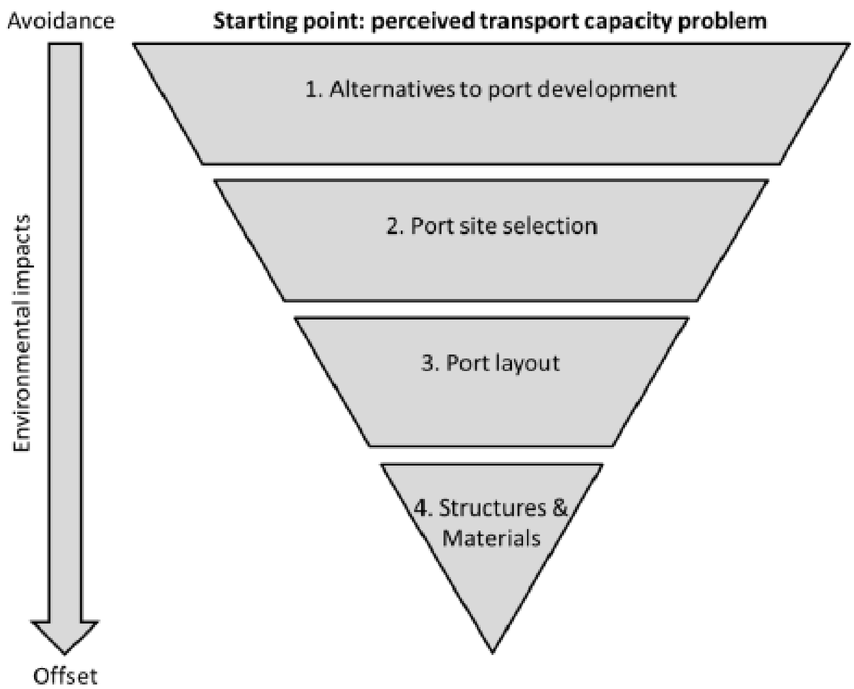


Figure 52: Ecosystem-based port design hierarchy (de Boer et al., 2018)

The framework helps to identify ecosystem based alternatives at 4 hierarchical levels of port planning and design: 1.) Consideration of alternatives to port developments to meet a perceived transport capacity problem (''no-port'' alternatives), 2.) Port site selection, 3.) Port layout selection, 4.) Selection of port structures and materials. Below a short elaboration of the levels is presented as described by de Boer et al. (2018).

A port development is one of the solutions to a perceived transport capacity problem, for example by expanding a brownfield or constructing greenfield port. A downside is the negative environmental impact in terms of air and water pollution, waste disposal, and dredging and construction works resulting in habitat loss. From an ecosystem perspective it can therefore be beneficial to explore alternative solutions that have less environmental impacts to resolve the perceived problem such as efficiency or utilization improvements of existing port infrastructure, increased cooperation between existing ports or improvements of other transportation modes.

If alternatives are limited or not sufficient to resolve the capacity problem entirely, it is assumed that port development is inevitable and the next step is selecting an appropriate site, which is basically the core of this site selection study. From an ecosystem perspective the site selection should account for ecological requirements such as: habitat connectivity, limited direct human interferences, endogeneity, species population viability, opportunities for threatened species, trophic web integrity, opportunities for ecological succession, zone integrity, characteristic (in)organic cycles, characteristic physical-chemical water quality and system resilience. Ideally, site selection is such that the natural local conditions enable port functioning so that little human interferences are required. Such a location would be naturally sufficiently deep for navigation, allows for sufficient maneuvering space and has sufficiently mild conditions (wind, waves, currents) to enable safe and efficient port operations. These considerations are discussed and applied in section 7.2.

After site selection, the port layout should be selected, which is highly dependent on the ambient natural conditions in terms of water depth, waves, wind and currents. From an ecosystem perspective, human interferences like deepening the port basin and access channels, land reclamation, or construction of breakwaters and quay walls should be avoided or minimized as much as possible. Traditionally seaport layouts consist of breakwater structures to provide shelter from ambient wave and current conditions. However, in mild coastal environments, open or unsheltered port concepts have been suggested as an alternative to traditional port layouts (described in section 7.1.5).

At level 4 ‘’structures and materials’’, the design freedom is constrained to choices related to the type of structures and materials to be used. Although possibilities to avoid environmental impacts at this fourth level are generally limited, ecosystem based design principles can still minimize environmental impacts. An example is eco-engineering: from a marine perspective breakwaters and quay walls add hard substrate for marine organisms to attach to. However, steep slopes, low structural complexity and high homogeneity of traditional port structures does not provide suitable conditions for the development of diverse biological assemblages. Solutions are found in artificial reef functions on breakwaters, ECOncrete to enhance the biological and ecological value of quay walls, artificial habitat creation, surface complexity enhancement and hanging ropes to increase the productivity and biodiversity in the hard-substrate environment (de Boer et al. 2018).

In principle, this 4-level hierarchy is carried out in this site selection research. The necessity for a port development (level 1) is described in section 3. Site selection (level 2) of this port is carried out in section 6. The type of port (level 3) and the used structures and materials (level 4) are determined and discussed in section 7. The following sections will describe some of the abovementioned considerations in more detail. The next page shows examples of different types of port lay-outs.

Figure 53 shows an example of an open port. Open ports make use of mild wave climates to avoid or minimize the construction of breakwaters and in this way minimize coastal impact. These ports have to allow for more downtime compare to protected ports, and need thorough wave studies to predict impacts on cargo handling.

Figure 53: Open port concept (port Akaba, Yemen)

Figure 54 shows an example of an offshore port partly build on a natural island with reclaimed areas. This concept is used to avoid space problems in congested areas, and is also a way of minimizing coastal impact nearshore. A large disadvantage of this concept is the necessity for a bridge towards the mainland.

Figure 54: Offshore natural island concept (Shanghai port, China)

Figure 55 shows an example of an offshore port on an artificial reclaimed island. This can be an option to use large natural available water depths and avoid large amounts of dredging. However, significant reclamation activities are required to create these island.

Figure 55: Offshore artificial island concept (Khalifa port, Dubai)

7.1.2 Dredging considerations

Aiming for a sustainable port design is strongly connected with the extent of the dredging and reclamation activities. Dredging and reclamation activities should be minimized in order to have the least (negative) impact and disturbance on the coastal system. In this section, some important considerations are described regarding the need for CAPEX/OPEX dredging.

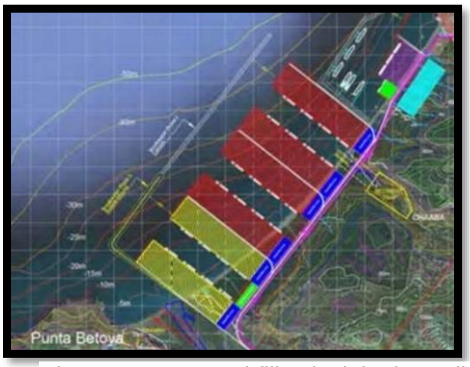


Figure 56: Cut-and-fill principle (Arcadis, 2013)

Cut-and-fill: In order to minimize dredging and reclamation works, a balance should be obtained between reclaiming land and dredging channels and port basins. The dredged material obtained by deepening the approach channel and the port basins should be used for reclaiming land for onshore activities, if suitable as construction material. The idea of cut-and-fill is shown in Figure 56, and applied in section 7.2. The yellow area in the figure denotes land for cargo handling. Cut-and-fill is applied because the piece of land in between the two yellow sections has to be excavated and dredged, and this dredged material can be re-used for filling the yellow sections which stretch into the sea. In this way dredging activities are minimized and the dredged material has a useful destination. Cut-and-fill is complex if the soil is very hard (which leads to high dredging costs) or very soft (which makes the soil unsuitable for reclamation, as is often the case in Myanmar).

Littoral drift: littoral drift, littoral transport or alongshore sediment transport is the transport of sediment along the foreshore and shoreface due to action of the breaking waves and the longshore current. If breakwaters are required, two basic considerations should be kept in mind:

- Along the alluvial coastline, the littoral transport occurs inside the breaker zone. Breakwaters reach beyond this breaker zone so they avoid sediment being deposited in the channel.
- If littoral transport occurs in both directions along the coast, breakwaters are also needed on both sides. Only when the wave climate is such that the littoral transport is unidirectional one breakwater may suffice. There are also possibilities for omitting a breakwater, which will be discussed in section 7.1.5.

So on the one hand the littoral drift needs to be blocked to avoid the approach channel and port basins from being filled with sediments. On the other hand, blocking the littoral transport can lead to (severe) erosion downstream as the bed load reverts to a stable situation, but may also offer possibilities for the natural reclaiming of land which can be used as beaches or wetlands. Often, the effect of a coastal port with breakwaters on the littoral transport is accretion of the beaches and mainland at the updrift side of the new port, and erosion of the beaches and mainland at the downdrift side of the port. In general, not (or at least as possible) disturbing the littoral sediment transport is always favorable.

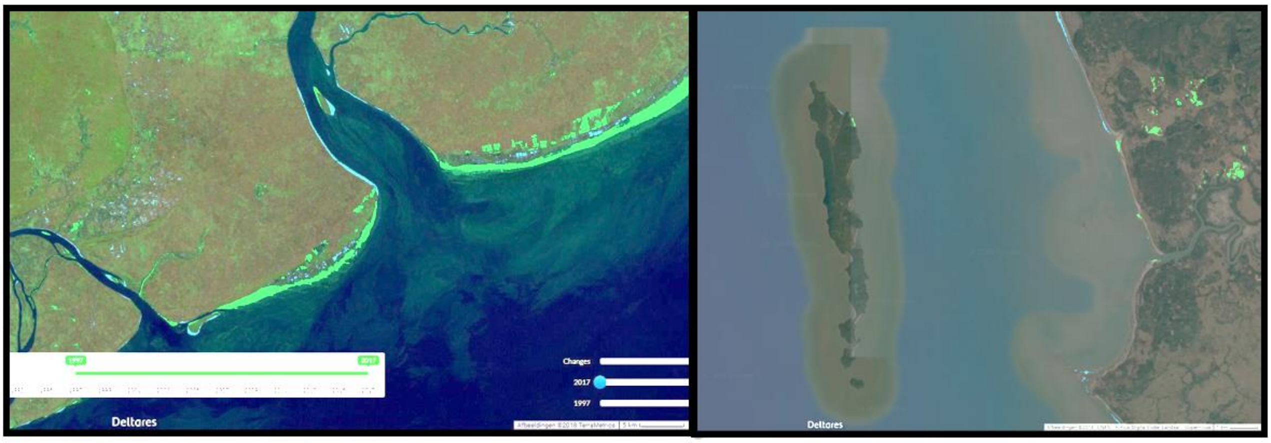


Figure 57: Blue areas denote erosion, green areas denote sedimentation (Deltares, 2018)

Figure 57 shows the erosion and accretion along the shoreline of the Yangon river mouth (left) and the Island of Kalegauk (right), which represents the proposed deep sea port location to the south of Mawlamyine. Due to the discharging river, Yangon is characterized by a dynamic morphological system with substantial accretion, up to 50 meters per year. Kalegauk Island is characterized by a stable morphological situation, with no substantial erosion or accretion. These data concerning the amount of accretion and erosion is an indicator for the required OPEX maintenance works.

Soil characteristics: the conditions of the seabed and the shallow subsurface are important for the assessment of dredging possibilities and use for fill material, as well as the design for structures. Figure 58 shows the British Admiralty Charts (ChartCo, 2018) of Yangon and Kalegauk Island. These charts are insufficient and need to be verified and supplemented by in-situ measurements (Ligteringen & Velsink, 2017) however, they provide a first indication of the soil characteristics of both locations.

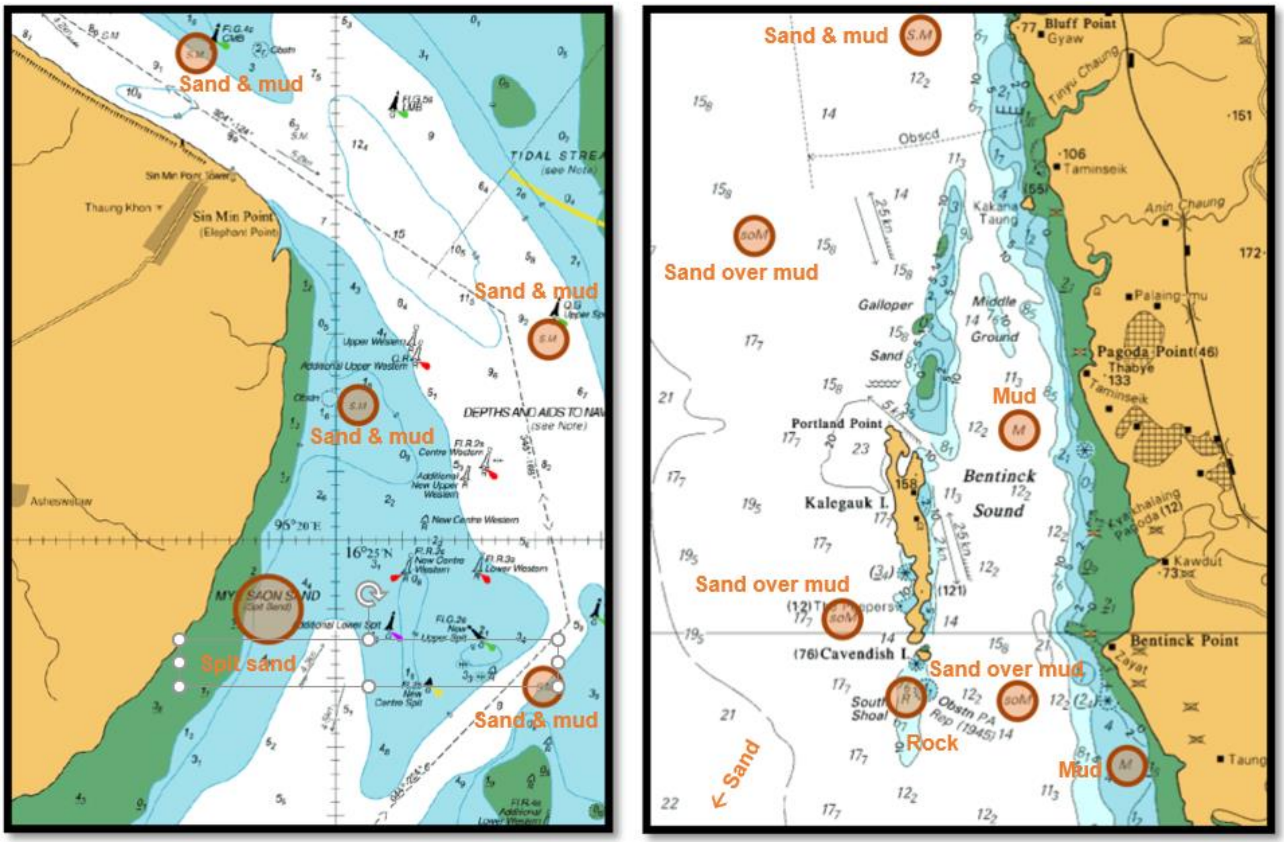


Figure 58: Soil characteristics Yangon river mouth (left) and Kalegauk Island (right) (ChartCo, 2018)

The orange circles in Figure 58 indicate the soil type. The Yangon river mouth consists mainly of mixed sand & mud, whereas the Kalegauk region is characterized by a sand layer on top of a mud layer.

Water depth: while the littoral transport is an important indicator of the amount of OPEX dredging, the natural available water depth is an important indicator of the amount of CAPEX dredging. Site selection always takes into account the available water depths, because dredging expenditures are (together with the costs for breakwater construction) a large part of the total port costs. As can be seen in Figure 58, the Yangon river mouth area has governing water depths of 9 meter in the channel, and about 4-6 meter at the coastline. Constructing a deep sea port should consider constructing the port further offshore where larger natural water depths occur. Kalegauk Island is located in an area where larger natural water depths occur, with a natural approach channel at the Northern side of the island, and governing water depths of 11-12 meter. These large natural depths cause less disturbance of the seabed and less dredging activities.

The full charts of Yangon river mouth area, Kalegauk Island, and several other locations can be found in Appendix K. In these charts, hydrographical and morphological information is presented of almost the entire coastline of Myanmar.

7.1.3 *Hinterland connections*

Hinterland connections are of vital importance for the functioning of a port and for the distribution of goods. Especially in this research, where the port will function as a gateway port for Myanmar's import and export. Hinterland connections have a large influence on the possibilities for sustainable functioning of a port. For the lay-out of a sustainable port, transport of energy and other products by a network of pipelines should be encouraged, which reduces the transport by truck, rail, and inland shipping. Besides, this network creates an infrastructure which makes it possible to cluster industrial activities (Port of Rotterdam, 2008).

Reducing road transport is an important consideration for a sustainable port. Road transport is by far the most polluting and dangerous type of transport, and therefore rail and inland water transport should be encouraged. Adequate facilities for inland shipping and rail transport are required. Port of Rotterdam is working on the modal shift, which means that the amount of cargo transported by trucks should decrease from 47% (2005) towards 35% in 2033 for the newest port development Maasvlakte 2. A stringent modal shift like the one from Rotterdam is not realistic for Myanmar, however the large inland waterway network should be used more extensively and efficiently. Myanmar can start with a large share of inland waterway transport, and use the existing Yangon Port to load and unload river barges. Besides, the existing rail network is planned to be upgraded which offers possibilities for cargo transport by rail. Concerning the lay-out of the port, rail and waterway transport should be encouraged.

Another consideration concerning hinterland connection comes forward when thinking of constructing the new deep sea port offshore. As mentioned in section 7.1.1, offshore ports are located on natural or artificial islands which are often not connected with the mainland. It is possible to ship the cargo with smaller vessels from the offshore port to the mainland or to other ports in the region, however it is more common to construct a bridge or causeway with possibilities for road and rail transport.

Additional research is needed to determine whether an offshore port is a feasible option for Myanmar. Offshore ports are complex (especially on artificial islands) and innovative port concepts, which can cause large expenses. Development banks and foreign countries invest substantial amounts of money into Myanmar's infrastructure development, so offshore port development should not be rejected upfront. However, if investors become enthusiastic and a feasible business case can be realized, offshore ports may be good options for the future.

7.1.4 Marine infrastructure and wave climate

The marine infrastructure is mainly determined by the alignment of the approach channel and the port basins. The following considerations are adopted from PIANC (2014) with regard to the approach channel:

- Shortest channel length
- Conditions and basins at either end of the channel (and stopping distance)
- Need to avoid obstacles or areas of accretion which are difficult or expensive to remove or require excessive (and hence costly) maintenance dredging
- Prevailing winds, currents and waves (calm water to hook up tugs)
- Avoiding bends, especially close to port entrances
- Environment on either side of the channel, such that ships passing along it do not cause disturbance or damage

Considering the level of detail of the lay-out in this research, two design principles regarding the location of berths and terminals will be taken into account:

- No berths or hard structures close to turning basins and in the stopping line of the vessels.
- Liquid bulk terminals have to be located at suitable safety distances from port activities and urban centers.

The design of the marine infrastructure starts with the alignment of the approach channel, which requires wind and wave data of the coastline of Myanmar. The wave data originates from an analysis of the wave climate along the Myanmar Coast by Kwant (2016). Kwant used hindcasts of wave data from a global wave model from 1979 to 2015. Those time series are analyzed with the peak-over-threshold method. The wave climate in the Bay of Bengal and the Andaman Sea is characterized by the South-West Monsoon winds. A distinct difference can be seen between the Andaman Sea and the Bay of Bengal in Figure 59. Due to the sheltering effect of the Andaman Islands, a lower wave height is found along Yangon and the southern Myanmar coast.

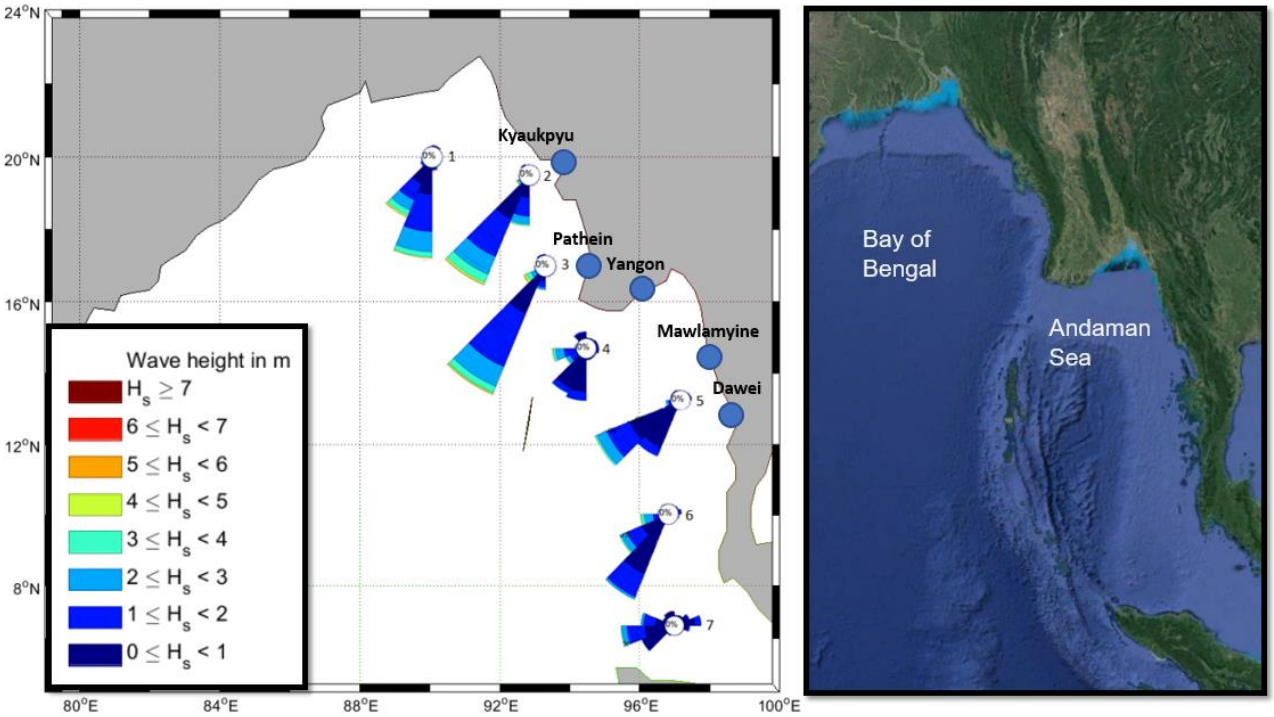


Figure 59: Significant wave height and direction in the Bay of Bengal and Andaman Sea (Kwant, 2016)

The above figure shows the dominant wave direction and significant wave height obtained from data from 1979 to 2015. It can be concluded that Yangon and Mawlamyine are located in a relatively mild wave climate, with dominant directs in the direction South-West to South.

7.1.5 Breakwater considerations and open ports

Protection of ports and vessel operation in ports against action of waves, currents and sediment transport can be realized in several ways. As mentioned earlier in section 2.1, Bruun (1989) states that a port site should be placed in a sheltered natural area such as behind an island or a shoal, in a deep natural bay or fjord, or in a sheltered lagoon, tidal entrance or estuary. These are all natural types of protection. Many ports are protected by using breakwaters, which stretches into the water to create calm port basins and prevent the sediment from filling the port basins. However, breakwaters are accompanied by large disadvantages:

- Breakwaters contribute to a significant part (up to 30%) of the total port construction costs.
- Breakwaters require rock blasting, shipping of material, and many construction vessels.
- Breakwaters disturb and change the coastal (eco)system by altering water and sediment flows.
- Breakwaters have a negative impact on the adaptivity of ports, because it is difficult and expensive to alter the breakwaters once they have been built.

Therefore research is ongoing concerning open ports: ports which are not protected by any form of natural protection or breakwaters. If the wave climate is mild enough, and ports allow for little downtime throughout the year, an open port as the port of Akaba presented in Figure 53 is an ideal option. As stated by Bakermans (2014), an open port minimizes the impact on the morphological environment, and offshore located ports may be inevitable when coastal zones are fully used for industrial and recreational purposes. Container terminals have the most stringent criteria as to environmental conditions, and it should be investigated whether open ports are possible for container terminals. The largest benefit of an offshore port is that the nearshore sediment movement feels little disturbance. Bakermans uses four concept lay-outs to explain the design aspects and possibilities of open container ports. The concepts are presented in Figure 60 and Figure 61. It should be noted that the boundaries of these concepts are in fact still breakwaters.

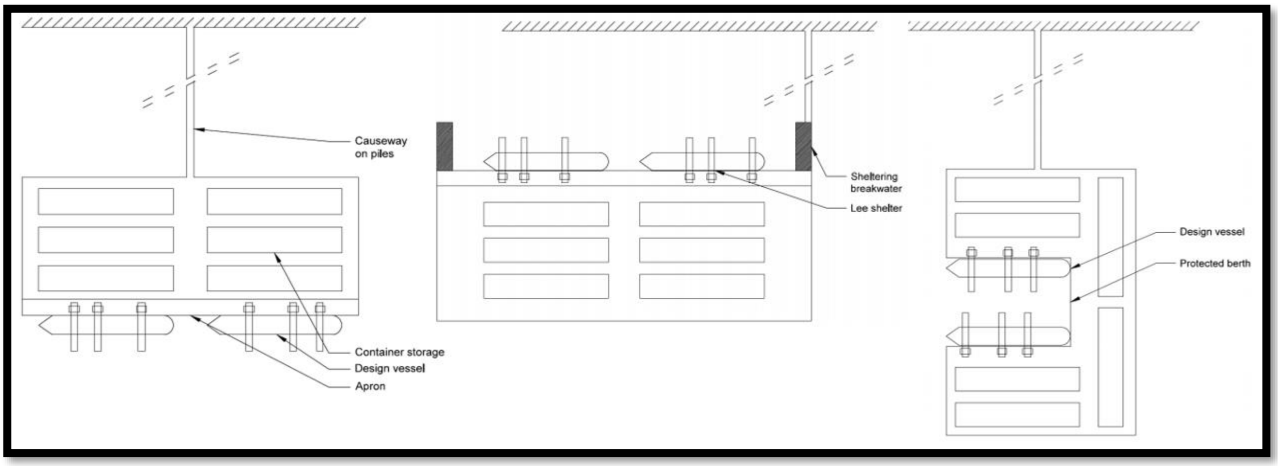


Figure 60: Reclaimed island concept and sheltering (middle and right) lay-outs (Bakermans, 2014)

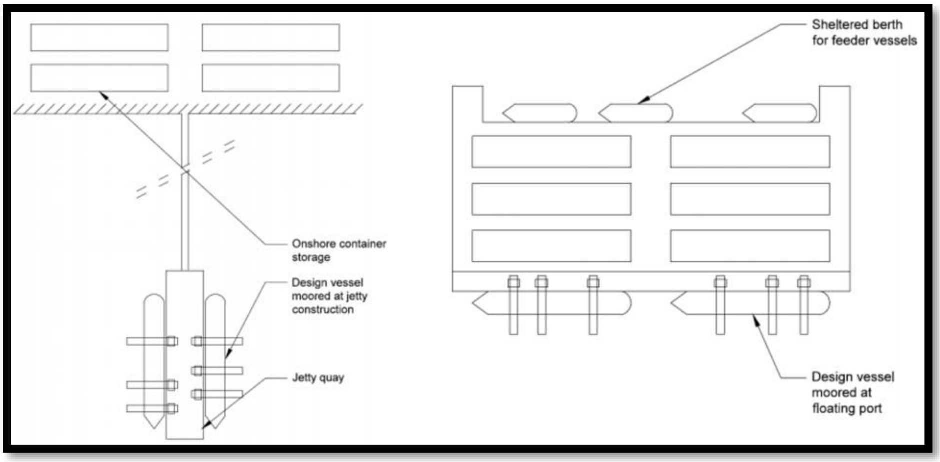


Figure 61: Jetty lay-out and floating lay-out (Bakermans, 2014)

7.2 Conceptual lay-out design

This section presents lay-outs and ecosystem-based (EBD) opportunities for four options (only the preferred options Yangon and Kalegauk Island from the analysis in section 6.3). For every option, some general considerations are mentioned, subsequently the main advantages and disadvantages are discussed, afterwards the proposed location is presented visually and finally the sustainable design principles (from section 7.1.1) which can be applied are described.

7.2.1 Option 1: Yangon nearshore location

- Because of the mild wave climate near the Yangon river mouth (section 7.1.4) and protection by the river banks, open port construction (section 7.1.5) may be possible.
- Due to the dynamic morphological situation, mud and sediment modelling is highly recommended. Most areas of the river mouth consists of mud (section 7.1.2), of which transport is hard to predict.
- Designing the port inside the river mouth provides opportunities for flushing the channel and port basin due to erosive areas. Outside the river mouth sedimentation areas are present (section 7.1.2).
- Ecosystem-based design principles may create added value by reusing dredged material for creating tidal flats and wetlands, both for protection of the river mouth as well as for creating new ecosystems.

Advantages	**Disadvantages**
Shortest connection to Yangon by road, rail and inland water transport (best IWT connection).	No railway and highway present at time of writing. Distance ± 50 km to city center.
Strong erosion indicates flushing of the channel and port basins which maintains the depth.	Natural depths of 8 – 10 m, so huge amounts of CAPEX dredging (and probably OPEX) are required.
Location provides opportunities for natural shelter and possibly absence of breakwaters.	Site is located at the river mouth which causes large flow velocities.
Few villages or inhabitants have to be removed and the hinterland will be protected to erosion.	This site is remote area, and therefore offers small availability of (skilled) labor in the proximity of the site
Port construction offers protection of land behind the port which is beneficial for people and villages.	Most of the sediment is sandy mud or mud, which is not always suitable as construction material.
CAPEX dredging of the approach channel and port basins increases discharge capacity of the river.	Accreting areas are not suited as port sites (section 7.1.2 and red cross in Figure 62)

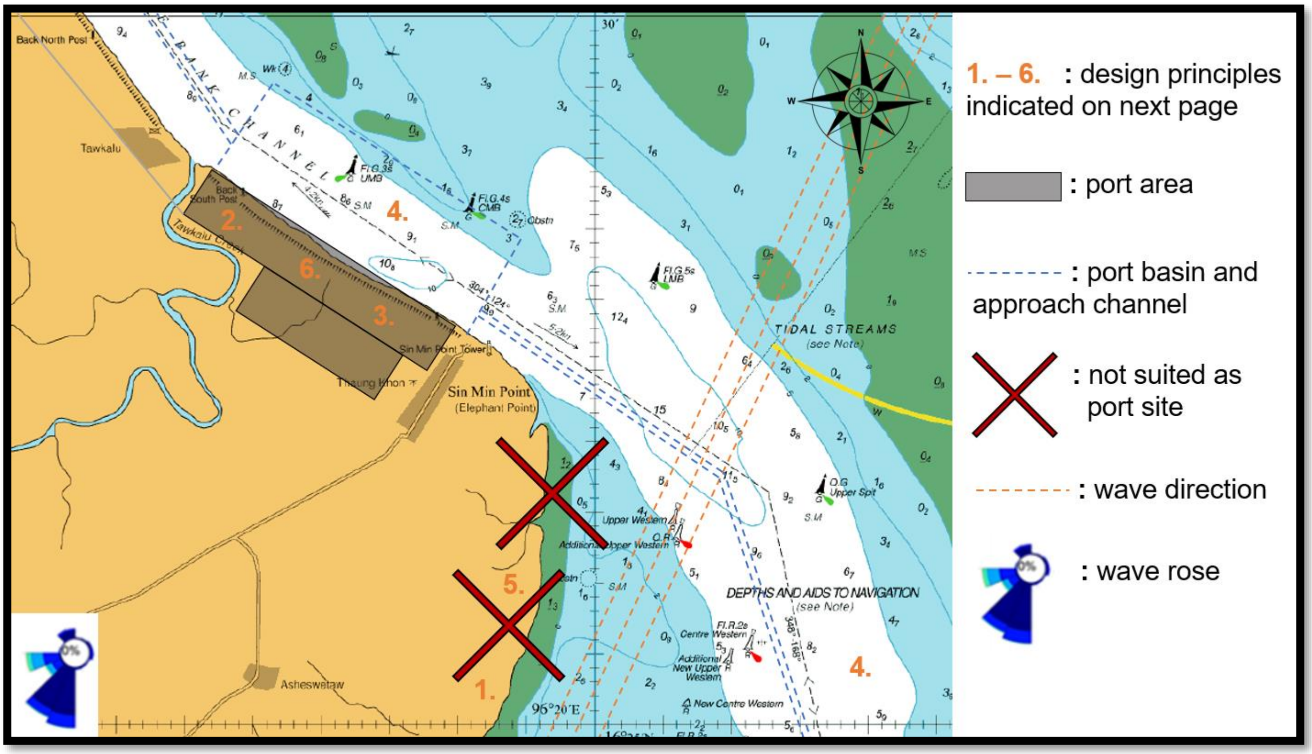


Figure 62: Option 1 - Yangon near shore at eroding river banks

Ecosystem-Based design principles are based on the results of the Ecosystem-tool, presented in section 6.3.6. To determine which design principles can be applied, the following method is applied:

- In Figure 63, focal areas (orange circles) are determined which indicate important positive or negative interrelations for which it is possible to maximize the positive impact, or to minimize the negative impact.
- The focal areas focus on the ecosystem services: 1. seafood/fisheries, 4. flood protection, 5. erosion/accretion regulation, 6. wildlife habitat and biodiversity, 8.recreation and eco-tourism. This corresponds to the stakeholder priorities with respect to Ecosystem Services (section 6.3.1 & Appendix I).
- The enumeration at the end of this page shows six ecosystem-based design principles which can be applied in this specific Yangon nearshore site (taken from section 7.1.1), in order to maximize positive impact in a focal area, or to minimize negative impact in a focal area.
- The orange numbers in front of the design principles correspond with the orange numbers in Figure 62.
- Additional information about Figure 63 can be found in section 5.4.4 & 6.3.6. Motivation for the scores can be found in Appendix J.

				1.	2.	3.	4.	5.	6.	7.	8.	9.
				Provisioning			Regulating & supporting				Cultural	
		Horizontal: Ecosystem services (UNEP, 2011) Vertical: Deep sea port elements		Seafood/fisheries	Fresh water storage and provision	Offshore energy	Flood protection	Erosion and accretion regulation	Wildlife habitat and biodiversity	Climate regulation	Recreation and (eco-tourism)	Aestethic and visual aspects
				2	0	2	3	3	2	3	1	1
1.	Deep sea port	Structural elements: quay walls, breakwaters, jetties	5	++	0	+	±	++	+	-	++	±
2.	Deep sea port	CAPEX dredging of approach channel & basins	5	0	0	0	+	+	-	-	0	0
3.	Deep sea port	OPEX dredging of approach channel & basins	5	-	0	0	++	++	--	--	0	0
4.	Deep sea port	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	±	0	0	0
5.	Deep sea port	Construction & maintenance	5	0	0	+	0	+	-	-	0	-
6.	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	0	--	-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8.	Operations	Marine activities: fishing, tugboats, sailing	3	-	0	0	0	0	0	0	+	+

Figure 63: Focal areas for the sub-region 'river mouth' applied to Yangon

Below, the relevant Ecosystem-based design principles are described, and between square brackets the number of the corresponding ecosystem service from Figure 63 (upper column in the figure) is denoted.

1. **Re-use of dredged material [4,5]**: dredged material for maintaining depths of 13 meter can be re-used for counteracting the erosion along the river banks, and to nourish wetlands and tidal flats.
2. **Fishery facilities [1]**: Facilitating fishery in the proximity of the port should be investigated because these fisheries will operate near the approach channel and port basins.
3. **Eco-engineering [1,6]**: Eco-engineering can be applied in every alternative, and additional research is needed to determine which types of eco-engineering should be applied.
4. **Seabed landscaping technique [6]**: Most probably the seabed exists of (large) sand dunes due to tidal forcing and large sedimentation. Opportunities for seabed landscaping may arise.
5. **Protecting or creating tidal flats [4,5,6]**: This design principle is related to the re-use of dredged material and can also be applied in every alternative. Wetlands already exist near the Yangon river mouth.
6. **Recreation [8]:** As Yangon is the main entrance of Myanmar for tourists, and Yangon is located in the proximity of this port site, cruise and ferry possibilities can boost (eco)-tourism.

These design principles are depicted in Figure 62 by the orange numbers.

7.2.2 *Option 2: Yangon offshore location*

Creating offshore ports may be an option to achieve more stable morphological situations and construct in larger natural water depths to minimize dredging activities. The situation at the Yangon river mouth seems like an example of a location which offers opportunities for an offshore port. Lay-outs for offshore ports should be constructed such that breakwaters are not needed, because these will become very expensive in deeper waters. For open water lay-outs, reference is made to section 7.1.5. When having a closer at look Figure 64 it becomes clear that an offshore port is probably not worth the effort because:

- 40 km offshore, the largest depths are only 9 – 10 meter. Only after approximately 70 km offshore, depths of 14 meter can be obtained. This creates large distances between the offshore port and the mainland.
- These large distances cause large expenses if a bridge or causeway is needed for further transportation of cargo by rail or road transport, but also causes larger logistic costs for barges and feeders. These distances also cause large exposure to storms in monsoons.

Advantages	**Disadvantages**
No impact on the nearshore sediment movement. The existing nearshore coastline is not disturbed.	A bridge (road/rail) may be needed to transport cargo towards the mainland.
Port uses available water depths to minimize dredging activities.	Large amounts of land have to be reclaimed for the port area which counteracts the dredging advantage.
Offshore options help in protecting vulnerable estuarine areas and habitats.	Large operational costs for transportation of staff
	Soft soils may cause large long-term settlements

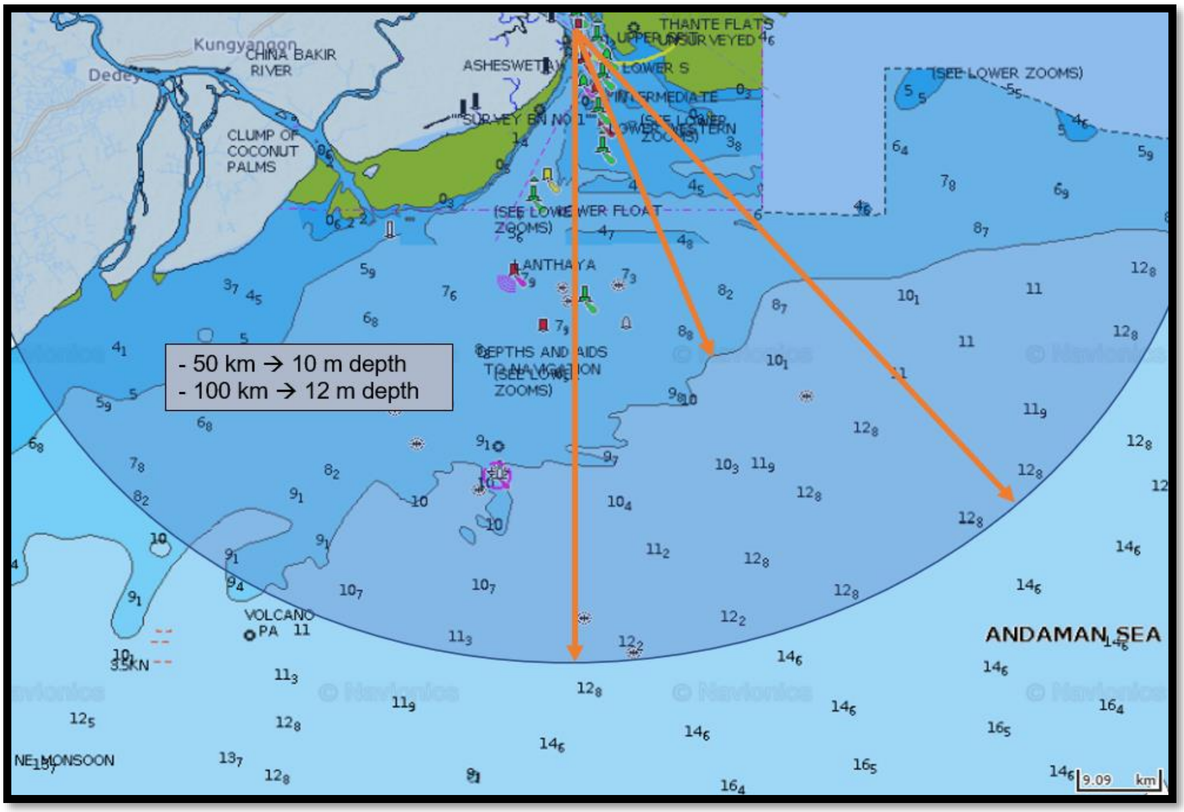


Figure 64: Option 2 - Yangon offshore site

An important consideration for an offshore port is the type of port. If the port will be a gateway for Myanmar, it is likely that most cargo has to be transported towards Yangon and Mandalay by rail, road or waterways. In this case, a bridge towards the offshore port is indispensable but impossible. If transshipment of cargo towards e.g. India, Thailand & Bangladesh is the main purpose of the offshore port, maintaining shipping routes may be sufficient and feeder vessels may transship the cargo from the offshore port to the mainland.

It can be concluded that an offshore port for handling Post-Panamax vessels is not feasible. This Yangon offshore option does not have large advantages compared to a suited site 150-200 km further.

7.2.3 Option 3: Kalegauk Island nearshore location

The second location which scored well besides Yangon in the MAMCA in section 6.3.3, is the location to the South of the city of Mawlamyine, near Kalegauk Island. Option 3 describes the nearshore design considerations for the location near Kalegauk Island. Important to mention is that it is unknown whether mangroves are present nearshore because different statements about mangrove presence have been found. It is therefore assumed that a small amount of mangroves is present. The ecosystem-tool for the sub-region 'mangroves' is used instead of the sub-region 'river mouth'. Important design considerations are:

- Open port possibilities: if the wave climate near the shore is mild because of sheltering effects from the island, it may be possible to design an open port. Again, reference is made to section 7.1.5 in which lay-outs are described which offer protection without using breakwaters.
- There is always some penetration of waves towards the coast, but a simple SWAN model can determine the wave climate near the coast, taking into account refraction and diffraction around the island. Subsequently, the operational limits as described in section 3.2.6 determine in combination with the allowed downtime of vessels if an open port may be possible.

Advantages	Disadvantages
Port can be placed in the lee side of the island.	Located relatively far away from Yangon.
Mangrove area near island is left intact compared with the option in section 7.2.4.	Replacement of one village is required for construction of the port area
Close connection with existing road an railway network at the eastern side.	
Small amount of relocation of villages and people	
The cut-and-fill principle can be applied due to relatively steep bed slopes and deep water nearsh.	

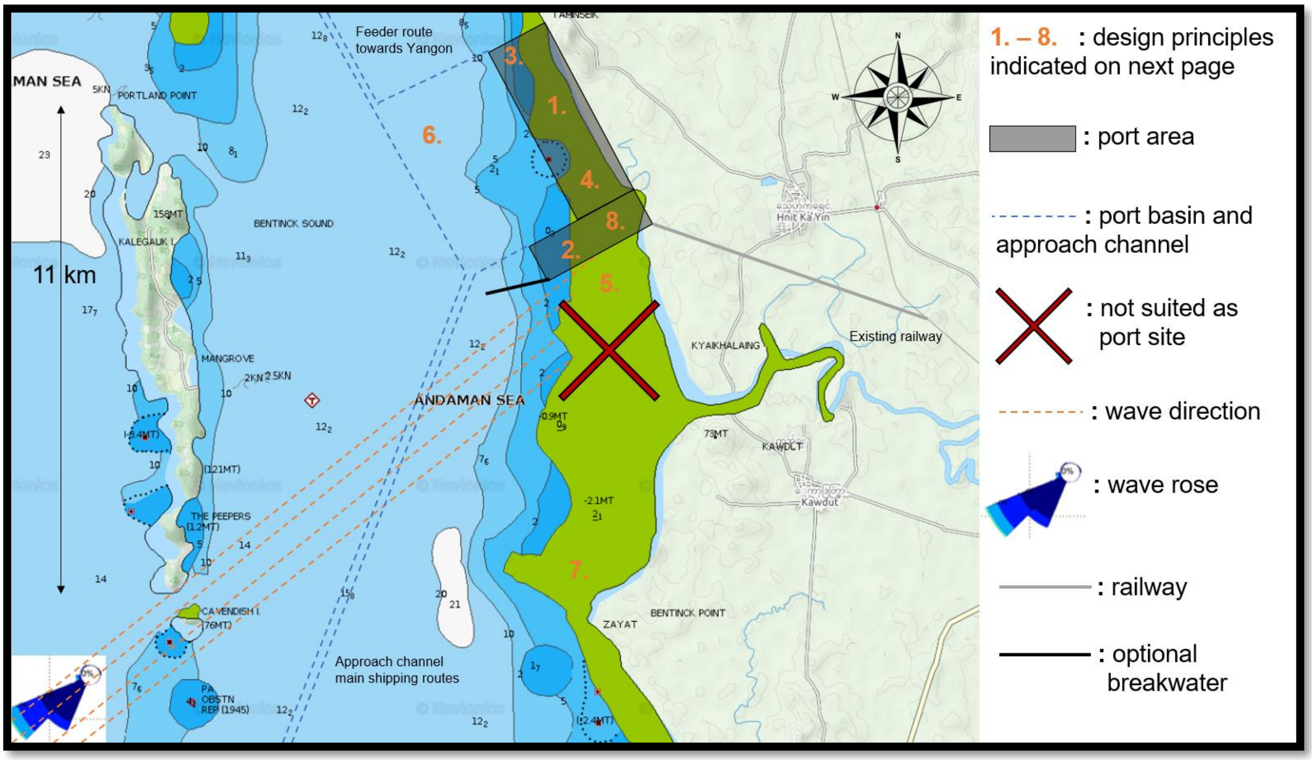


Figure 65: Option 3 - Kalegauk Island nearshore site

If breakwater protection is required, it may be possible to construct a small breakwater almost perpendicular to the coast. Ecosystem-Based design principles are again based on the results of the Ecosystem-tool, and the same method is used for determining suitable design principles as in section 7.2.1:

- In Figure 66, focal areas (orange circles) are determined which indicate important positive or negative interrelations for which it is possible to maximize the positive impact, or to minimize the negative impact.

- The focal areas focus on the ecosystem services: 1. seafood/fisheries, 4. flood protection, 5. erosion/accretion regulation, 6. wildlife habitat and biodiversity, 8.recreation and eco-tourism. This corresponds to the stakeholder priorities with respect to Ecosystem Services (section 6.3.1 & Appendix I). It can be seen that especially the port elements CAPEX and OPEX dredging have a significant impact at this location.
- The enumeration at the end of this page shows eight ecosystem-based design principles which can be applied in this specific Kalegauk island nearshore site (taken from section 7.1.1), in order to maximize positive impact in a focal area, or to minimize negative impact in a focal area.
- The orange numbers in front of the design principles below correspond with the orange numbers depicted in Figure 65.
- Additional information about Figure 66 can be found in section 5.4.4 & 6.3.6. Motivation for the scores can be found in Appendix J.

		Horizontal: Ecosystem services (UNEP, 2011) / Vertical: Deep sea port elements		1. Seafood/fisheries	2. Fresh water storage and provision	3. Offshore energy	4. Flood protection	5. Erosion and accretion regulation	6. Wildlife habitat and biodiversity	7. Climate regulation	8. Recreation and (eco-tourism)	9. Aestethic and visual aspects
				Provisioning			Regulating & supporting				Cultural	
				4	0	0	5	5	5	5	3	3
1.	Deep seaport	Structural elements: quay walls, breakwaters, jetties	4	++	0	+	-	-	+	-	++	±
2.	Deep seaport	CAPEX dredging of approach channel & basins	3	0	0	0	--	--	--	-	+	0
3.	Deep seaport	OPEX dredging of approach channel & basins	2	-	0	0	-	±	--	--	+	0
4.	Deep seaport	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	+	0	0	0
5.	Deep seaport	Construction & maintenance	5	0	0	+	-	0	+	-	0	-
6	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	-		-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8	Operations	Marine activities: fishing, tugboats, sailing	4	-	0	0	0	0	0	-	+	+

Figure 66: Focal areas for the sub-region 'mangroves' applied to Kalegauk Island

Below, the relevant Ecosystem-based design principles are described, and between square brackets the number of the corresponding ecosystem service from Figure 66 is denoted.

1. **Reuse of dredged material [4,5]**: Cut-and-fill and re-use of material can minimize dredging activities. Besides, the steep bed slope minimizes dredging. Sandy material may be suitable as construction material.
2. **Designing on piles [5,6]**: Absence of a breakwater in combination with port structures on piles minimizes disturbance of the coastline. It should be investigated whether this construction on piles is possible.
3. **Fishery facilities [1]**: Small areas near the boundaries of the port site can be designated as fishery area.
4. **Eco-engineering [1,6]**: Relatively mild wave and current climates offer wildlife habitats. Eco-engineering on structural elements may replace destroyed wildlife habitats.
5. **Protecting or creating tidal flats [4,5,6]**: the green areas in Figure 65 are mainly tidal flats. Dredged material can be used to strengthen these flats and improve coastal protection.
6. **Seabed landscaping [6]**: because of a relatively balanced morphological area, seabed landscaping can speed up recovery of habitats.
7. **Environmental compensation [6]:** to compensate for lost parts of habitat, protected seabed areas can be realized.
8. **Recreation [8]:** the coastline of Mon State offers scenic coastal areas which can be used as touristic areas in the near future.

7.2.4 Option 4: Kalegauk Island offshore location

This option at Kalegauk island near Mawlamyine offers large opportunities for creating an open, offshore port on a natural island. In this way, the coastline with its tidal flats and scattered mangroves is left intact and there is no need for an expensive breakwater which disturbs the area because of protection by the natural island. For this option, reference is made to the similarities with the offshore Yangshan port in Shanghai, presented in Figure 54. The main design considerations for this option are:

- The effect of waves on the lee side of the island should be known. Firstly because this decides if protection by e.g. breakwaters is necessary, and secondly to determine if the wave impact is small enough compared to the wave impact on land in order to justify the offshore option.
- Breakwaters do not pose large threats to the morphological situation at this location, because it is a stable area which is morphologically in balance, which possibly minimizes OPEX dredging (Figure 57).
- This offshore option makes perfectly use of the natural large water depths (up to 12 m) near the island, both for the port basin and the approach channel (which minimizes CAPEX dredging).
- It should be investigated whether a bridge towards the mainland is necessary. The span is approximately 9 km, which is more feasible than the Yangon offshore option. Again, the type of port is crucial for this choice, as a transshipment port may operate without a bridge and functions with barging and feeders.
- The bridge can be located at the Northern part or the Southern part of the island. This depends on the alignment of the approach channel. In this case, it is chosen to place the bridge at the Northern part of the island, because it can be expected that the largest vessels enter the port from the main shipping routes between Singapore and Colombo. Smaller feeders may be able to sail under the bridge towards Yangon.

Advantages	**Disadvantages**
High quality road connection and rail connection from the mainland towards Yangon.	Located 440 km away by road and rail from Yangon, and 200 km by sea (by coastal feeders)
Offshore location causes the least negative impact on the coastline and causes less dredging activities.	Most probably a bridge or tunnel connection is required to the mainland for rail and road transport
Stable morphological area, no river outflows, and no severe erosion or sedimentation problems	Negative impact on small areas of mangrove forest
Natural depths of 12-15 m, both for approach channel and port basins. Steep slopes near island.	
Breakwater not directly necessary at lee side of the island. Relatively less impact on the coastal system.	
Different soil types are present in the surrounding area (sandy mud, sand, rock)	

Another important advantage of offshore ports (depending on the type of offshore location) is related to the ecological value of coastal zones. Coastal zones are often characterized by a higher habitat richness and biodiversity than the offshore zone due to larger heterogeneity. These richer habitats do not have to be displaced in case of an offshore extension (de Boer et al. 2018). In the case of Kalegauk Island, it is not known whether the coastal zone at Kalegauk Island has the same habitat richness compared to the nearshore coastal zone.

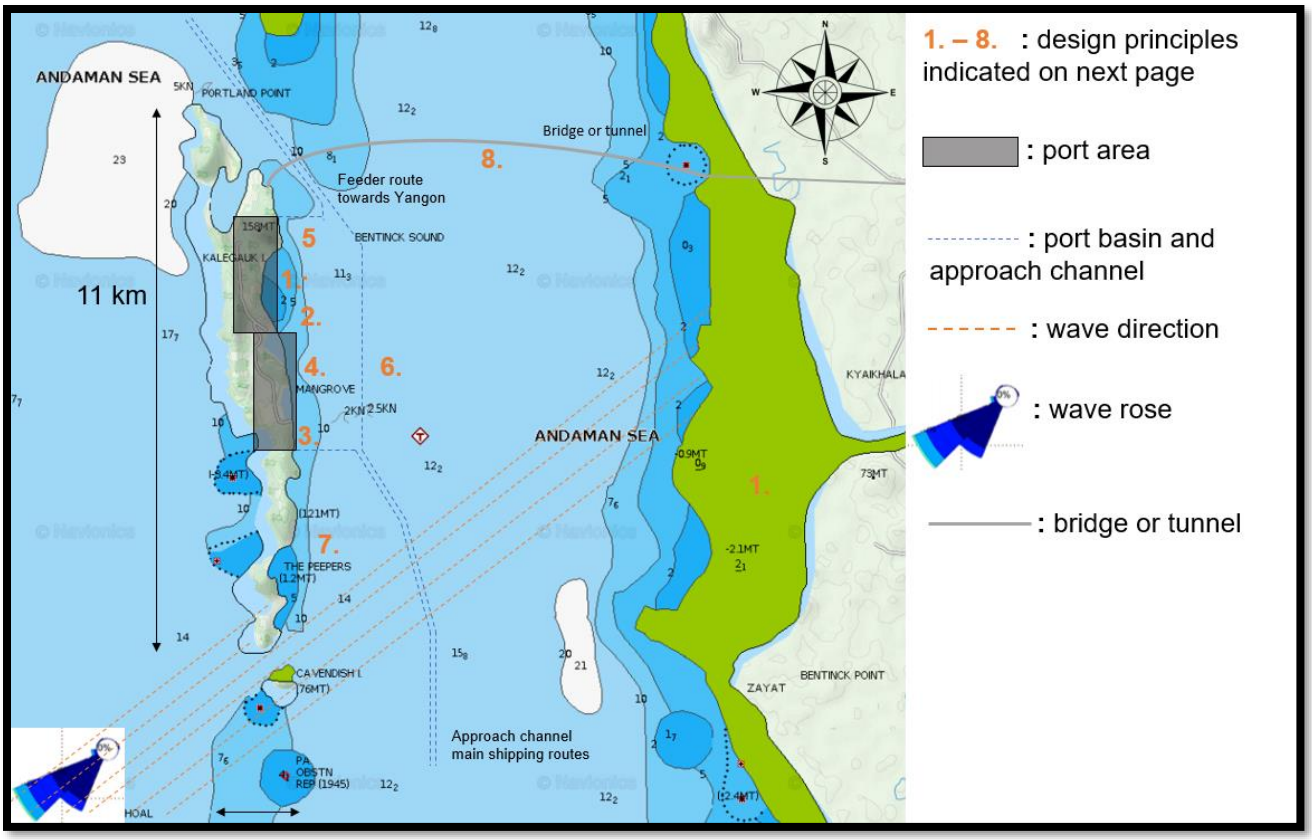


Figure 67: Option 4 - offshore option Kalegauk island

This option uses the same focal areas as option 3, presented in Figure 66, and the same method for determining the suitable deign principles. The following Ecosystem-based design principles can be applied:

1. **Reuse of dredged material [4,5]**: cut-and-fill and re-use of material can minimize dredging activities. The material is sandy near the island, and the steep slopes and shape of the island offer good possibilities for the cut-and-fill principle as can be seen in Figure 67.
2. **Designing structures on piles [5,6]**: mangroves are present on the coastline, and structures on piles contribute in minimizing the deviation of water and sediment flows which keeps the conditions for mangroves constant.
3. **Fishery facilities [1]**: a small fishermen village already exists on the island, and port development can offer small jetties and warehousing for the local community, as compensation for possible relocations.
4. **Mangrove preservation [1,4,5,6,7,8]**: mangroves on the island should be preserved or replaced to the onshore mangrove areas. It is not known whether it is possible to leave the mangroves intact on the island.
5. **Eco-engineering [1,6]**: same as in section 7.2.3.
6. **Seabed landscaping technique [6]**: because of a relatively balanced morphological area, seabed landscaping can speed up recovery of habitats.
7. **Environmental compensation [6]**: to compensate for lost parts of habitat, protected seabed areas can be realized.
8. **Recreation [8]**: a bridge or tunnel to the island offers possibilities for (eco)-tourism by allowing cars and buses to enter the island. Besides, cruise ships and ferries can use the island for tourism purposes.

It is important to mention that the sustainable design principles mentioned in section 7.1.1 have to be investigated in more detail in order to know whether they are practically and economically attractive. Some of the principles are only used in pilot projects and some of them have never been used in practice. However, they provide starting points for new ways of thinking and for new sustainable design ideas for port development.

8 CONCLUSION & DISCUSSION

This section presents the proposed strategy for deep sea port development and site selection in Myanmar, which is the conclusion of this research and the answer on the main research question *''which long-term deep sea port site selection and development strategy should Myanmar adopt, in order to fulfil their growing demand for maritime shipping, taking into account current trends in sustainable deep sea port development and site selection?''.* This strategy could prove useful for the Ministry of Transport and Communications in Myanmar. The results of the research steps (section 1.5) required for answering the main question are not discussed separately since these results have been discussed in the previous sections. The main conclusion of this research can be seen as a merging of results and conclusions drawn in previous chapters and includes the site selection process, site recommendations, design & lay-out recommendations and major challenges associated with deep sea port development in Myanmar.

The results and conclusions of this report provide a basis to form recommendations for the Ministry of Transport and Communications (MOTC) in Myanmar, with respect to site selection and deep sea port development. The tools used for research and the conclusions drawn, can guide MOTC, while providing practical information and carrying out their own site selection process, if required. The conclusion and answer on the main research question will be discussed in the coming sections, but can be summarized as follows:

Myanmar should focus on two favored sites for port development, instead of a scattered port development situation with 6 (possible) developments in the actual situation. Yangon is, and will remain the economic center of the country. Moreover, it has the best hinterland connectivity and many planned infrastructural developments in the coming years. There is large pressure and support for creating a deep sea port near Yangon. However, physical restraints show that Yangon region does not offer suitable sites for a deep sea port which is able to accommodate Post-Panamax vessels or even larger. Yangon is a crucial port and must be part of the port strategy, however it suffers from two major restricting aspects, which also apply for Thilawa port: the large amount of sediment discharged by the Yangon river requires continuous maintenance dredging activities, and the largest natural water depth of the river is only 9 m. Even offshore until a distance of 100 km, no large natural water depths and sandy bottoms can be found. Yangon port should maintain its current activities, and this appears best in combination with a deep sea port near Kalegauk Island. This site will accommodate the large vessels and by means of transshipment by sea, road and rail, Yangon will be served. Kalegauk island is not only suitable because of constructional reasons, it is also a good location because of a close connection with Thailand and the Greater Mekong Sub-region. So a combination of ports which complement each other is recommended in which Kalegauk Island serves as main gateway (largest and deepest port able to accommodate the large vessels) to Myanmar and Yangon as an extended gateway or feeder port (feeder vessels transfer cargo to large ships at Kalegauk). This is beneficial because:

- The site near Kalegauk Island is connected with Yangon by a decent road connection, a rail connection and a coastal connection. It offers natural deep water, a stable morphological area and natural shelter possibilities.
- Kalegauk Island is situated in between the city of Mawlamyine and Dawei, which are both connected with two road corridors through the Greater Mekong Sub-region which offers additional hinterland and markets. This will be a help throughput (cashflow) which is always critical to a new port, and may attract investors. It also offers a road or railway alternative for the congested Streets of Malacca.

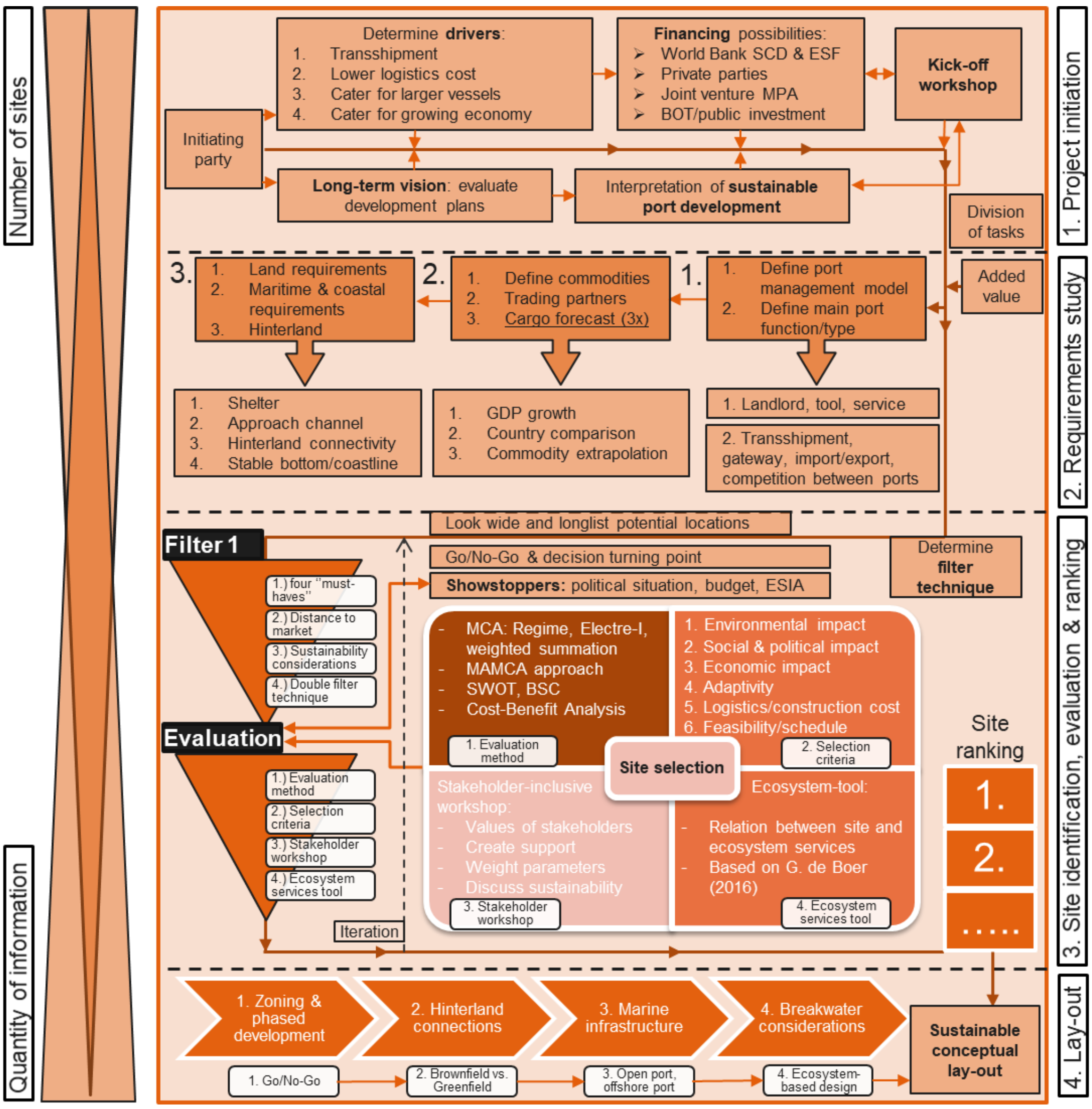
An alternative for the site near Kalegauk Island is Nga Yoke Kaung area near Pathein in Ayeyarwady region. This option is under investigation by Myanmar Maritime University (section 4.4.4), and offers similar advantages as the site near Kalegauk Island.

8.1 Framework: site selection process

The conclusions regarding the site selection process are based on the case study and the site selection framework developed in chapter 5. During the case study it became clear that Myanmar is in need of a more comprehensive site selection and port development policy, with less foreign influence. After validation of the framework in section 5.5 and application of the framework in section 6, it can be concluded that the framework is applicable in Myanmar and can be used by the Ministry of Transport and Communications (MOTC). Additional explanation for this framework can be found in section 5 and in a short manual in section 6.4.

The essence of the framework is to show which processes, methods and considerations play a role in site selection. The framework is not a fixed tool, because decision-makers should for instance decide whether they think a SWOT-analysis would be more useful compared to a MAMCA-approach.

A site selection process which is technically, commercially and sustainably sound, will not only increase support for future projects, but also increases the know-how of site selection and port development, as well as the chance of obtaining funding from development banks. The strategy for deep sea port development and site selection, is based on the framework presented below:



The framework is developed based on fieldwork in Myanmar and is in first instance meant for application in Myanmar. However, the framework is constructed such that it is also applicable in other countries by omitting Myanmar-specific aspects in the framework.

It should be concluded that this research opted for a broad and sustainable site selection approach, but crucial criteria for site selection will still remain water depth, connectivity and distance to a market. These are necessary prerequisites, before proceeding with a more detailed site selection. However, the framework shows that it is possible to use different filters, and that there are many more relevant criteria and considerations for selecting a site.

With respect to port development in Myanmar, the country should focus on import and export instead of fulfilling a transshipment role. The main motivation for port development is to cater for the growing economy of Myanmar itself, which means serving its own market and hinterland. During the case study it became clear that Myanmar does not have own policy with respect to site selection of its coastal ports. Two possible explanations for selecting sites of deep sea port development came forward:

- Neighboring countries China, Thailand and India try to allow direct access to the Bay of Bengal for their land-locked regions. They plan, finance and construct ports focused on catering their own needs.

- In the final months of the military regime, the government decreed two laws to establish three special economic zones (SEZ) based on unknown considerations, which cannot be withdrawn.

This confirmed the expectation upfront stated in section 1.2 that the selection of current sites did not (or too briefly) consider commercial, logical and sustainable development from a Myanmar wider perspective. Until now, the sites are mainly based on (geo)political considerations.

Another conclusion concerning the site selection process is related to the second problem statement in section 1.2. This statement stated that a framework which integrates a stakeholder-inclusive approach and the concept of ecosystem services, together with traditional and commercial site selection drivers is missing. Integration of the stakeholder-inclusive approach and ecosystem services as carried out in this research can be summarized with the flowchart presented below:

The relevant ecosystem services are described in section 5.4.4. Subsequently the stakeholders are involved and their needs and values with respect to ecosystem services are mapped during the workshop (section 6.3.1 & Appendix I). The interrelations between the ecosystem services and the specific port sites are analyzed in the ecosystem-tool in section 6.3.6, to map the interrelations where negative impacts should be minimized and where positive impact should be maximized. Focal areas from this ecosystem-tool form the basis for applying ecosystem-based (EB) design principles.

8.2 Framework application: site recommendation

One of the research objectives was formulating site recommendations for deep sea port development in Myanmar, based on results from application of the framework. A simple, but maybe one of the most important conclusions concerning future deep sea port sites is the fact that this research cannot point out the 'best site' for a port. Every site has its own pro's and con's, and the most optimum site should be chosen based on the actual drivers for port development, and the selection criteria and weight parameters determined by the needs and values of the stakeholders in Myanmar. These needs require more research, especially due to the complex political situation of the country and the (growing) influence and interest of foreign countries in Myanmar. The tools, data and conclusions from this research serve as guidance and equipment for the Myanmar decision-makers, in order to formulate their own decisions concerning deep sea port development. For example, the Ministry of Transport and Communications can use the excel sheets with impact matrices, weight parameters and the ecosystem tool, to determine their own 'optimum site'. Before elaborating upon the site ranking from the framework application, some general conclusions can be formulated.

Finding the best gateway to Myanmar and Yangon

Myanmar's coastline can roughly be divided into a North-Western stretch which is located in the Bay of Bengal, and a Southern stretch which is located in the Andaman Sea (Figure 59). The North-Western stretch consists of the sites Sittwe, Kyaukpyu, Thandwe and Pathein, while the Southern stretch consists of the sites Mawlamyine, Dawei, Myeik and Kawthoung (Figure 12). In this division, Yangon is situated in the middle, however Yangon is connected to the Andaman Sea and is therefore classified in the Southern stretch. From the site selection process in section 6, it became clear that there are important differences between these two coastal stretches and it turned out that in general, the Southern stretch is substantially better suited for deep sea port development compared to the North-Western stretch because of the following reasons (in sequence of decreasing importance):

1. **Arakan mountain range:** The Arakan mountain range (Figure 36) stretches from the Northern borders with Bangladesh and India towards the Southern Irrawady Delta near Pathein. These mountains are densely forested, hardly accessible and act as a natural barrier between Central Myanmar and the Bay of Bengal. This causes poor hinterland connections towards the central parts of Myanmar and Yangon. This is included in the site selection in the first filter criterion 'connectivity' (section 6.1).

2. **Corridor developments:** Following section 4.1 and 4.1.1, there are developed corridors in the south to Thailand and Vietnam, but little or no corridor (road/rail) developments planned in the North-Western states of Myanmar and the Arakans. It is concluded that this coastal stretch will remain isolated and hinterland connectivity will not improve in the coming years. This disadvantage is included in the site selection by evaluating alternatives based on connectivity criteria in the first filter and on accordance to policy in the MAMCA.

3. **Mild wave climate Andaman Sea:** Following section 7.1.4, the Andaman Sea is sheltered by the Andaman islands, causing a milder wave climate in the Andaman Sea compared to the unsheltered Bay of Bengal. Milder wave climates cause less problems for vessels and offer open port opportunities.

4. **Complex political and humanitarian situation:** Rakhine state covers almost the complete area between the Bay of Bengal and the Myanmar part of the Arakan Mountain Range. Some areas have specific problems which would probably deter investors, or may cause infrastructural developments to be postponed. This situation is considered as a showstopper in the first filter in section 6.1.

Following the site selection process in section 6, the first filter resulted in a short list with Pathein, Yangon, Mawlamyine and Dawei, which corresponds to the sites at the Southern stretch. These four sites are evaluated in detail with a Multi-Actor Multi-Criteria Analysis. Depending on the point of view of the decision-maker, an environmental, social, economic, or cost-based cluster can be chosen, resulting in different rankings due to the different priorities indicated by different weight parameters (section 6.3.5) between the clusters:

- The **environmental** cluster: 1. Mawlamyine, 2. Yangon & Pathein, 3. Dawei
- The **social/political** cluster: 1. Yangon, 2. Mawlamyine, 3. Pathein, 4. Dawei
- The **economic** cluster: 1. Mawlamyine, 2. Yangon, 3. Pathein, 4. Dawei
- The **cost-based** cluster: 1. Mawlamyine, 2. Pathein, 3. Yangon, 4. Dawei

Constraints of Yangon as deep sea port site

Mawlamyine and Yangon shape the overall top 2. Yangon seems like a logical choice for deep sea port development, as it is the economic center of the country with the best hinterland connectivity. In principle, Yangon should have been filtered out in the first filter in section 6.1 based on its small water depths, but Yangon is kept in the site selection process due to the large pressure and support for Yangon as a deep sea port site and to show that it is not the most optimum site for deep sea port development (section 7.2), despite pressure and insights from many Myanmar stakeholders. Yangon suffers from the following physical restraints:

- From the city center towards the Yangon river mouth, maximum water depths of 9 - 10 m are available.
- Offshore from the river mouth, depths of 14 m occur only after 100 km and further away.
- Outside the Yangon river mouth, large sedimentation problems arise (accretion of ± 500 m land/year).
- Soil in the Yangon river (mouth) consists mainly of mixed sand and mud, which causes large settlements.

Constructing the deep sea port in Yangon would result in a very inflexible and unsustainable port. A port with large negative impacts, large changes in the ecosystem, and large amounts of required maintenance works does not fit in the scope of this research. After omitting Yangon as deep sea port site from the cluster-based enumeration discussed earlier, a new and clear site ranking becomes obvious which is the same for all four clusters: 1.) Mawlamyine (near Kalegauk Island), 2.) Pathein (Nga Yoke Kaung area), 3.) Dawei (SEZ). For the final site recommendation, reference is again made to the two strategic objectives for maritime development as stated in the Transport Masterplan written by JICA and the MOTC:

- **Strategic objective 1:** Enhance port capacity of Yangon port (including Thilawa area) to meet sharply increasing cargo demands and to reduce dwelling time of cargoes and ships in the port.

- **Strategic objective 2:** Develop a deep sea port that can accommodate large vessels in trunk routes to support the increasing maritime transport, at reasonable cost to users in the Central North-South corridor.

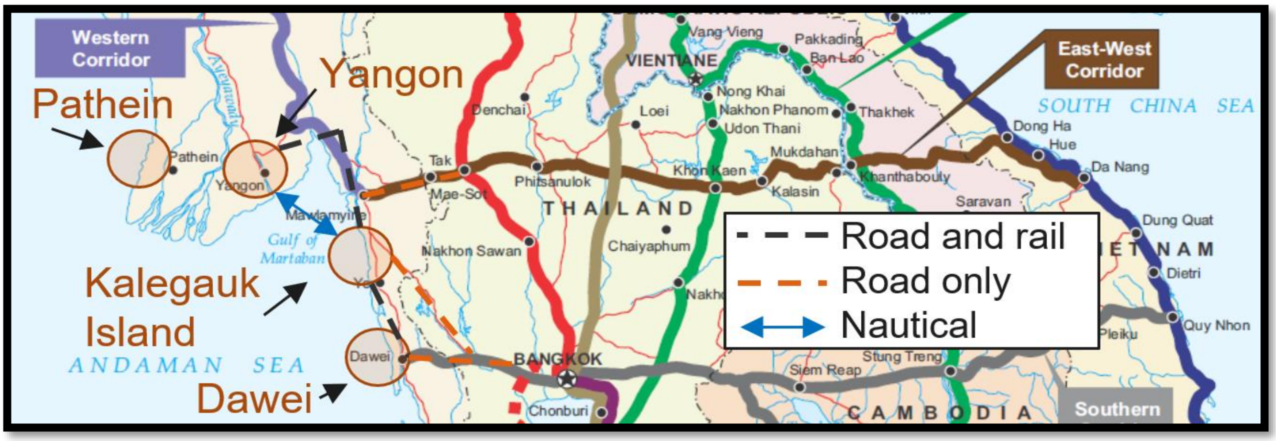
Integrated Yangon-Mawlamyine port: gateway to Myanmar and GMS

It can be seen that although Yangon is not suitable as deep sea port development site, it is a crucial port and must be part of the plan. Yangon port and Thilawa port should maintain and strengthen its current activities (strategic objective 1), and this appears best in combination with a deep sea port near Kalegauk Island (to the south of Mawlamyine). This port will accommodate the large vessels (strategic objective 2) and Yangon (functioning as a feeder port or extended gateway) and its hinterland will be connected to it by sea, road, and rail. Kalegauk Island is not only suitable because of physical, constructional reasons, it is also a good location because of a close and high quality road connection with Thailand and the Greater Mekong Sub-region. This delivers a direct income source and attracts investors (contributing to one of the biggest challenges which is financing the projects). A combination of ports which complement each other is recommended in which Kalegauk Island serves as the main gateway and Yangon as an extended gateway (see figure on next page). This is beneficial because:

- The site near Kalegauk Island is connected with Yangon by a decent road connection, a rail connection and a coastal connection. It offers natural deep water, a stable morphological area and natural shelter.

- Kalegauk Island is situated in between the city of Mawlamyine and Dawei, which are both connected with two road corridors through the Greater Mekong Sub-region which offers additional hinterland and markets. This will be a help throughput (cashflow) which is always critical to a new port, and may attract investors.

The large vessels will call at Kalegauk Island, and an extended gateway in Yangon, connected by road, rail, and a waterway for coasters will handle cargo for Yangon and its hinterland. This combination of ports has great opportunities and similar combinations can be found in the Greater Mekong Sub-region in Thailand, Cambodia and Vietnam, as described in section 4.1 (and Figure 13). Examples can also be found in Europe, with the combination of seaports in Antwerp and Rotterdam, and a large inland port which serves its hinterland in Duisburg (section 4.1).



Kalegauk Island serves two purposes in this way: transshipment and serving its own hinterland in the Greater Mekong Sub-region, as can be seen in the above figure. Kalegauk Island is not the only option for a deep sea port, as Nga Yoke Kaung (Figure 37) near the city of Pathein (ranked second in this study) can also serve as deep sea port. This option is briefly discussed in section 4.4.4. This site is recommended by Velkavrh & Naing (2018), however Kalegauk Island seems like a better location because of the following reasons:

- The sailing distance between Pathein (Nga Yoke Kaung) and Yangon is 430 km versus 200 km between Kalegauk Island and Yangon. Transshipment by coasters from Kalegauk is therefore cheaper.
- Besides the longer distance, the sailing route from Pathein (Nga Yoke Kaung) to Yangon is partly situated in the unsheltered Bay of Bengal. This may cause hindrance to navigation, especially during the monsoon.
- Road connectivity of Nga Yoke Kaung is underdeveloped and there is no rail connection (yet).
- Pathein (Nga Yoke Kaung) does not have (connection to) a hinterland, compared to Kalegauk Island which has direct access to Thailand, Cambodia and Vietnam by the EWEC.

Similar to Pathein, Dawei (to the south of Kalegauk Island) which ranked number three during the site selection process, could also serve as main gateway. It has similar water depth characteristics compared to Kalegauk Island, however it is located approximately 100 km further away from Yangon which makes transshipment more complex and more expensive, compared to transshipment from Kalegauk Island. Besides, Dawei is located in an unsheltered coastal area with large mangrove presence, and the GMS corridor connecting Dawei with Bangkok, Cambodia and Vietnam is postponed and still in the planning stage (Figure 18). This reasoning (and a more detailed motivation in Figure 45) makes Kalegauk Island a more attractive location. Nevertheless, it can be concluded that all three sites Mawlamyine, Pathein and Dawei are suitable locations because these sites remained after the filter with four key criteria and the filter concerning distance to market.

In summary: Yangon port is becoming saturated in the coming years and continue with pushing Yangon to further develop its port is useless because it is not suitable to become the main gateway and welcome Post-Panamax vessels up to 14 m of draught. Both nearshore and offshore, no suitable sites can be found based on hydraulic and morphological considerations. Yangon port should be part of the future port development, and can function as an extended gateway or feeder port of a potential main gateway near Kalegauk Island (near the city of Mawlamyine) or Nga Yoke Kaung (near the city of Pathein). After analysis, it is found that Kalegauk Island is most suited because of hydraulic and morphological considerations, and it can serve both a transshipment function as well as serving an own hinterland within the Greater Mekong Sub-region.

It is interesting to examine what would have been the results with ‘traditional site selection’. This is quite complex because there is not one method for traditional site selection and this research does not elaborate upon a framework or process for ‘traditional site selection’. However, if site selection would have been based on frequently described aspects such as water depth and natural shelter only, Kyaukpyu would be the chosen site. If site selection would have been based on the fastest development, Kyaukpyu and Dawei would have been chosen. And if site selection would have been based on commercial aspects only, Yangon would have been chosen because it is the most logical location when looking at the distance to the biggest market of Myanmar. The added value of the site selection framework in this research is the process of actively involving stakeholders and using a new way of creating sustainable development: Ecosystem-Based management. The sites have been chosen by taking into account a broad range of aspects, including environmental, social and economic ones. It shows that site selection is not just common sense and that there are many different drivers and methods for selecting the most optimum site. Lastly, it presents a concrete and visual representation of possible sustainable design principles which will hopefully be acknowledged in Myanmar.

8.3 Final lay-out & biggest challenges

The final lay-outs and the main considerations can be found in section 7.2. Three examples of alternative lay-outs are provided, but the decision-makers should decide between these alternatives, based on the mentioned advantages, disadvantages, and their own expert judgement. Based on the complete section 7 about alternative lay-outs, several conclusions can be drawn.

As stated in the previous section, Yangon region offers no potential sites for development of the main gateway port. Section 7.2.1 showed that the largest nearshore water depths can be found at an eroding outer bend close to the river mouth, with maximum depths of 9 - 10 m. These depths may be sufficient for development of an extended gateway which accommodates smaller coaster vessels, as explained in the previous section. In Figure 62, it is indicated that the morphological processes should be taken into account. Outer river bends in the Yangon river mouth possess the largest depths and natural flushing of sediments takes places in these bends. Just outside the river mouth, large sedimentation problems occur and port basins will be filled with sediments continuously.

Similar to the nearshore location, offshore alternatives near Yangon (section 7.2.2) are not suited for development of a main gateway port. The small natural water depths act as a showstopper, especially in combination with the soil characteristics and sedimentation problems. The lack of large depths can sometimes be resolved by searching for depths further offshore. In the case of Yangon however, this is not an option because the minimum required depth of 12 m can only be found at a distance of 100 km offshore (Figure 64), which would also mean construction of bridge or tunnel of this length (if required). Depths of 14 – 16 m are found at a distance of 130 km offshore and even further. This distance is comparable with the proposed site near Kalegauk Island (sections 7.2.3 and 7.2.4). It is therefore not logical and sustainable to create such a unnatural port system offshore near Yangon, if a suitable site near Kalegauk Island is available at a comparable distance to a possible extended gateway near Yangon.

Two promising alternatives can be found near Kalegauk Island (sections 7.2.3 and 7.2.4). An offshore option on the natural Kalegauk Island, and a nearshore option to the east of this island is proposed. Both options are promising, and offer opportunities for ecosystem-based design principles. At these locations, natural channel depths of 12 – 17 can be found and basin depths of 12 – 14 m. The author has provided lay-outs, advantages, disadvantages and sustainable design principles for these alternatives, and the decision-makers should decide themselves which alternative they think is more valuable and suitable.

In order to establish a new deep sea port development, the biggest challenges need to be acknowledged. These challenges are not site-specific but hold for all sites. The following challenges came forward during the case study, or are mentioned during stakeholder consultations:

1. **Development of road connections to key ports**: road connectivity in Myanmar is underdeveloped, as a consequence of years of lack of investment in infrastructure. Roads are often unpaved which makes them seasonally accessible and not made for heavy duty transport. As described in section 4.1.1, several infrastructure initiatives are underway to connect Myanmar with the Greater Mekong Sub-region and to develop its own infrastructure network. Bad connectivity affects port developments negatively in two ways. Firstly because road connectivity is important because transport of cargo by rail or inland water transport only is impossible. Secondly because constructing ports need large amounts of construction material which has to be transported to the proposed location. This is mostly done by road transport.

2. **Creating a more attractive and favorable investment climate:** an instable political situation, humanitarian crises in Rakhine state, lack of clarity on policies and the absence of long-term policy hinders long-term foreign investments and cause financing problems for large infrastructural projects. Myanmar does not have sufficient resources to finance these projects itself and therefore a more attractive and favorable climate should be created for (private) investors and development banks.

3. **Change focus from short-term towards long-term port development policy and masterplans**: this challenge is related to the previous one, because absence of long-term policy and masterplans does not strengthen trust of investors. Myanmar has nine coastal port locations, and new developments also depend on the long-term objectives of individual ports and the competition between ports.

4. **Keep control of influence of neighboring countries:** foreign help and investments should of course be appreciated and embraced, but a strong influence of neighboring countries can lead to neglect of the needs and values of Myanmar itself. Foreign influence should therefore always be checked for its contribution towards Myanmar’s needs and values.

8.4 Discussion

This discussion elaborates upon exceptions and shortcomings from the conclusion or aspects of the conclusion which need additional explanation. It is important to mention that just blindly following the framework does not directly results in a ranking of sites. In principle, the framework is developed to support policy-makers with site selection, and it makes visible which criteria and methods are important and useful in site selection. Some technical and port engineering knowledge is required because some steps in the framework demand input from the user. Port planning is a multi-disciplinary subject and needs expertise from various disciplines. A requirements study needs transport economists and mapping stakeholders needs and values in a workshop (a format for a workshop is provided in section 5.4.3 and Appendix I) asks for stakeholder management.

Speaking of the workshop, the stakeholder mapping needs additional explanation. For the multi-stakeholder workshop in this research, stakeholders were selected in consultation with Arcadis and based on the experiences and network of the Arcadis supervisors in Myanmar. However, many considerations are related to selection of the workshop participants. The most important consideration for selecting stakeholders is the degree in which the stakeholder is able to influence the decision-making. Deep sea port developments in Myanmar are a Union Level decision, which means that the highest level of government (nationwide Union level government) need to decide on this and regional governments need permission from the Union government. The workshop did not involve Union level decision-makers from the MOTC (impossible to involve these decision-makers for a small workshop like this one moreover), while these decision-makers probably have different views and priorities than regional stakeholders. For a definitive solution to the site selection problem, a different set of stakeholders may be required.

During the multi-stakeholder workshop, weight parameters are determined individually or in pairs, to be able to carry out multi-criteria analyses per stakeholder. The research supervisor from Arcadis C. Parkinson recommended to determine the weight parameters on a group level by reaching consensus, because this represents the priority of the whole group of stakeholders. This is rather complex because in Myanmar culture, higher level employees or directors from the private sector express their opinion stronger than lower level employees. 'Group weight parameters' would thus express the priorities of a small group of stakeholders, and therefore it is chosen to determine the weight parameters individually or in pairs. Another remark from Arcadis is related to the origin of the stakeholder priorities. The participants in the multi-stakeholder workshop were all living in Yangon and working for an organization or government department in Yangon, which may cause biases in the (questionnaire) results. For the validity of the results, it would have been better to involve stakeholders from different regions and start discussions in mixed groups. Stakeholders from regional governments only are most likely interested in developing ports in their region. Another solution may be organizing the multi-stakeholder workshop in the four coastal states, and compare the results of these workshops.

Those weight parameters are used in a Multi-Actor Multi-Criteria Analysis (MAMCA), an extension of the classic Multi-Criteria Analysis. During a progress meeting, it was initiated to investigate whether a Balanced Scorecard could be used to evaluate site alternatives. The Balanced Scorecard is developed as business management model in order to map and measure the key processes (financials, internal business processes, customers, learning and growth) and indicators of a company's performance. The Balanced Scorecard could be a useful evaluation method in location studies like this research, although not many applications can be found in literature yet. This tool is investigated, however the site selection process was already carried out by means of the MAMCA. This MAMCA-approach could have been used more effectively, by using individual strategic objectives (or selection criteria) of the stakeholders. This shortcoming does not have large negative influence on the validity of the results, because from the results of the validation of the selection criteria (Table 30) it turned out that the stakeholders all agreed with the usability and significance of the selection criteria.

During the workshop, described in section 5.4.3, an interactive stakeholder session was organized in order to map priorities and values of stakeholders concerning ecosystem services. Valuation of the ecosystem services was carried out by two different methods. Firstly by using four group discussions, in which the stakeholders had to choose between two services in a series of pairwise comparisons. The second method for valuing importance of ecosystem services concerned an individual questionnaire. The complete results can be found in Appendix I. The results of the individual and group ranking show large similarities, and the top three is shaped by fuel/offshore energy, flood protection & erosion/sedimentation regulation, and seafood provision.

In section 7.2, principles and measures to maximize the benefits from the ecosystem services flood protection, erosion/sedimentation regulation, seafood provisioning and wildlife/biodiversity are mentioned. However, the ecosystem service fuel and offshore energy is not mentioned yet, while this ecosystem service is valued most important by the Myanmar stakeholders. This ecosystem service is mentioned separately because sustainable energy is often related to wind energy which may be possible for all options. Besides, a controversial aspect of the ecosystem service 'fuel/offshore energy' is related to its gas and offshore oil reserves. Natural gas comprises 90 percent of the total oil and gas sector and Myanmar is the 10th largest producer of natural gas globally. It has estimated gas reserves of 3 trillion cubic meter and oil reserves of 50 million barrels (UK Trade & Investment, 2015). Therefore it is possible to link deep sea port sites to the opportunity to exploit nearby offshore oil and gas fields, and increase the production of fossil fuels. Although this may provide revenues for Myanmar, it is in conflict with aiming for sustainable site selection. When taking into account the ecosystem service offshore energy, Myanmar should focus on sustainable sources of energy like solar and wind energy. According to the author, fuel and energy is very important for the countries development, however Myanmar owns mainly natural gas. It is more important to develop the country in a controlled and sustainable way between the strong influence of foreign countries. Climate regulation, seafood provisioning, maintaining wildlife and habitats and erosion/sedimentation regulation are the important services. These services are important for sustaining the abundant natural resources and boost the economy of the country.

9 REFLECTION & RECOMMENDATIONS

A reflection on the lessons learnt and insights gained during the research, follows. This section ends with a concrete list of recommendations supplementing the conclusions, both for further research as well as for the Ministry of Transport and Communications in Myanmar.

9.1 Multi-stakeholder workshop

An important part of the research was the multi-stakeholder workshop. This workshop served as source for data as well as an opportunity to bring public and private stakeholders together for capacity building on deep sea port development. Participants of the workshop responded positively at the end of the workshop:

"This kind of workshop benefited us to evaluate the concepts that should be priorities to be valued most for the country's development in sustainable ways," said Daw May Soe Aung, Assistant Director, Department of Marine Administration, Myanmar.

"This workshop considerably advanced the knowledge sharing between the different organizations about the port sector development in our country as it brings the authorized persons all together to this workshop," said Prof. Daw Sanda Naing, Head of Port and Harbour Engineering Department, Myanmar Maritime University.

She added: *"The cooperation between the government, business stakeholders and the academic institutes should be prioritized and MMU is well-prepared to contribute the country's development in related sectors by doing projects and research if the opportunity to involve deeply is taken into consideration. If sustainable financial support can be provided by government, MMU will be able to contribute to the country's development substantially."*

Besides these statements from two participants, several insights were gained during the workshop:

- Most stakeholders showed an individualistic way of thinking, in which they emphasized their own benefits, instead of an integrated way of thinking.
- The focus during the workshop was on short-term thinking instead of long-term thinking. For example, low priority was given to recreational possibilities and impact on tourism. Most stakeholders did not know the positive impact tourism can have on communities and regions on the long term.
- In Myanmar, workshops and game structuring methods needs methods in which people have to state their opinion in small groups or individually. Large group discussions are led by one or two persons. This situation became clear during a site visit at Pathein Regional Government, where the Regional Minister of Transport and Communications, and all department directors were present. Arcadis tried setting up a group discussion with all 15 participants, however only a dialogue with the regional minister was possible.
- The support and drive is available for sustainable development, however most participants do not know where to start, and what a clear definition of sustainable development is.
- In Myanmar, people still like workshops and recognize the value of workshops, which should be used for more capacity building and education on topics like sustainable development.

Additional results and statements can be found in the questionnaire results in Appendix I.

9.2 Research process

The research process went satisfactorily however, some remarks should be made. The first contact with Arcadis Myanmar was on the 3th of May 2017. During the first 4/5 months, some preliminary research and desk study was possible using documents provided by Arcadis Myanmar, but setting up a clear research objective remained complex until the first week of the research in Myanmar. In the first days, everything became clear and this confirmed that a researcher really needs to work 'on site' when an in-depth case study is conducted, especially in a country like Myanmar where project documentation or literature is not always documented and publicly available.

This relates to concerns at the beginning of the research whether it was even possible to obtain data and documents about port policy, decision-making, past port projects, but also points of view from stakeholders with respect to the national port development situation. These concerns were not completely justified. Port policy, decision-making documents, and past port project documents were indeed poorly documented and not always publicly available, but during stakeholder consultations most of the stakeholders were willing to help in obtaining data or provide contact information of people who were able to help. In this way, the involved stakeholders and workshop participants had a great contribution in obtaining the necessary data for finalizing this research.

Location problems like the one addressed in this research often require a lot of data and these studies can take months or even years when carried out by specialized consulting firms. Therefore scoping within these studies is of crucial importance. The scoping (which includes the determination of the site selection criteria which in turn determines the data required) could have been done at an earlier stage of the research process in order to obtain more time for data gathering. If the scoping (site selection criteria) of the location study was finished halfway of the fieldwork, the second half of the fieldwork could have been used for structured and goal-oriented data gathering. In order to do so, also the stakeholder consultations should have been carried out earlier, which was almost impossible because before starting these consultations the researcher needed to become familiar with the topic. Looking back, perhaps the fieldwork should have started one month later or should have lasted one month longer. Nevertheless, this did not create any problems even though planning of before starting actual research is complex.

One aspect that did bring some problems is the literature study. During the proposal phase of this research, the literature study focused on site selection and trends in sustainable port development. By that time, it was already known that the location study and framework development was going to contain an evaluation method (e.g. Multi-Criteria Analysis). Hundreds of evaluation methods exist. However, because a Multi-Criteria Analysis (MCA) is a widely accepted and transparent evaluation method, and also recommended by Arcadis, this method was chosen quite early in the process leaving other evaluation methods outside the scope of the research. The multi-stakeholder workshop during the fieldwork resulted in weight parameters for six site selection criteria which were input for a MCA. At that moment, the choice for a MCA was already fixed. After the fieldwork additional literature study was carried out on different types of MCA, but also on alternatives like the Multi-Actor Multi-Criteria Analysis (MAMCA) and the Balanced Scorecard. Aspects of the MAMCA are applied and two different MCA's are carried out, however literature study on these subjects before starting the fieldwork would have resulted in a more well-considered choice of the evaluation method.

9.3 Recommendations & lessons learnt

Several recommendations are made in sections 8.1, 8.2 & 8.3. This section presents additional recommendations for the decision-makers in Myanmar: the Ministry of Transport and Communications (MOTC), and Myanmar Port Authority which is the responsible department for deep sea port development. Besides this, recommendations for additional research are included.

Recommendations for the Ministry of Transport of Communications

- **Use the framework as a guide:** this report provides recommendations with respect to the optimum site, however this should be seen as guidance. MOTC can use the framework, together with a specific evaluation method and the ecosystem-tool, in order to develop Myanmar's own deep sea port development process and to prioritize the large number of actual port development plans. This can also be used as a test, to check whether the results of this research are in compliance with results of MOTC.
- **Select sites and develop ports from stakeholders needs and values:** the multi-stakeholder workshop in this research brought important stakeholders in the port sector together. It became clear that many different needs and values are present amongst the stakeholders, and that mixing of private and public stakeholders contributes to support for a large development like a deep sea port. Based on stakeholders needs and values, support for site selection can be obtained and added value can be created.
- **Develop long-term port masterplans & national port development policy:** this is also mentioned as one of the biggest challenges. Absence of long-term post masterplans does not only hinder long-term investment plans, but also causes uncertainty with respect to the direction and objectives of the national port development policy. If ports do not have individual masterplans, their main tasks and future operations are unknown which complicates port planning. E.g. if Dawei port will be the main gateway for all agribulk cargo and is developing bulk terminals, Yangon Port can decrease its agribulk activities and increase its container activities. A national port development policy will also assist in determining whether Myanmar will act as a transshipment hub in the future. Until now, it is not possible to determine whether this is viable.
- **Encourage and embrace sustainable development:** Myanmar has thousands of kilometers of beautiful coastlines, wetlands and mangrove forests. Port development often has a negative impact on the environment, but by using sustainable design principles like the ones addressed in section 7.1.1, a port does not only have to cause negative impact. Possible positive social and environmental impacts need to be acknowledged. Sustainable development is an ongoing process without a predefined end goal, and as Myanmar stands at the beginning of large reforms and infrastructural developments, now is the time to create support for sustainable development.

Recommendations for additional research

- **Research into most optimum port combination:** In this research, it is concluded that a port combination with Yangon and Kalegauk Island is most suited. However, the combinations Yangon – Pathein, and Yangon- Dawei can also be suitable locations. Additional research which combinations is the best one.

- **Application of framework on case studies:** As stated earlier, the framework is developed by using a Myanmar case-study. The framework may be applicable in other countries as well, however this should be tested. Testing of the framework leads to further refinement and additional knowledge of site selection.

- **Filter long list based on SDG's:** The Sustainable Development Goals provide a complete overview of seventeen 'sustainable site selection criteria'. If these SDG's can be valued, they can serve as site selection criteria in a first filter. These SDG's are acknowledged worldwide and can create strong support for future deep sea port projects if the developer can prove the SDG's are satisfied in a positive way.

- **Inclusion of cost estimations:** Costs are almost neglected in the site selection process as, but remain one of the most important site selection criteria. Rough estimations are carried out based on the water depth, hinterland connectivity and the need for shelter. During additional site selection research, a first cost estimation should be carried out and to investigate whether this changes the ranking of sites. Costs could be included in the first filter for example.

- **Making visible the benefits of a sustainable port:** Support for sustainable development can be created by showing the long-term (financial) benefits of a sustainable port compared to a traditional port. Several methods exist for valuation of ecosystem services, like 'direct market valuations', 'revealed preference approaches', and 'stated preference approaches' (section 2.3.2). If the ecosystem services in Myanmar can be valued for different sub-regions, it would be possible to attach monetary values to the negative and positive impact of ports in the coastal zones.

- **Study into evaluation methods for location studies:** As stated in section 9.2, this research used a MAMCA for evaluation of different port sites. It is unknown whether this method (or variants of the MCA) are the best methods for location studies. Research can therefore focus on application of different methods on a specific case study in order to compare results and processes and provide recommendations on the best methods for location studies. One of the possible evaluation methods which is recommended for further investigation, is the Balanced Score Card method.

- **Monetary valuation of Ecosystem Services:** Section 2.3.2 describes methods for economic valuation of ecosystem services. These methods are not used in this research, however these methods can be of great significance in additional site selection research. When the ecosystem services are valued in monetary terms, different sub-regions or port sites can be compared based on these monetary values and in this way the ecosystem services form are stronger integrated in the site selection process.

Lessons learnt

The most important lessons learnt from this research is that Myanmar is in a very dynamic port development situation with numerous ongoing studies, plans, and large influence from foreign countries. Myanmar itself has not enough financial assets to develop its own ports and should therefore partly rely on foreign assistance, keeping in mind that Myanmar's needs should not be forgotten. Large pressure is put on Yangon as deep sea port site, however it is just not a feasible and sustainable site to serve as main gateway. The Ministry of Transport & Communications should study the port combination with a main gateway at suitable locations (Kalegauk, Pathein, Dawei) in combination with a large inland port in Yangon. Another important lesson learnt is that a consultant should not provide politically correct recommendations. So although it may not be the most desired conclusion for a large group of stakeholders, Yangon is not suited as deep sea port which can handle the large Post-Panamax vessels which are likely to arrive in the coming years.

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APPENDIX A : EBM MARINA DEVELOPMENT

The framework presented below is adopted from G. de Boer (2016). The framework describes ecosystem-based management for sustainable marina development. The Marina-Ecosystem interrelations matrix tool is adapted and used in this research in sections 5.4.5 and 6.3.6.

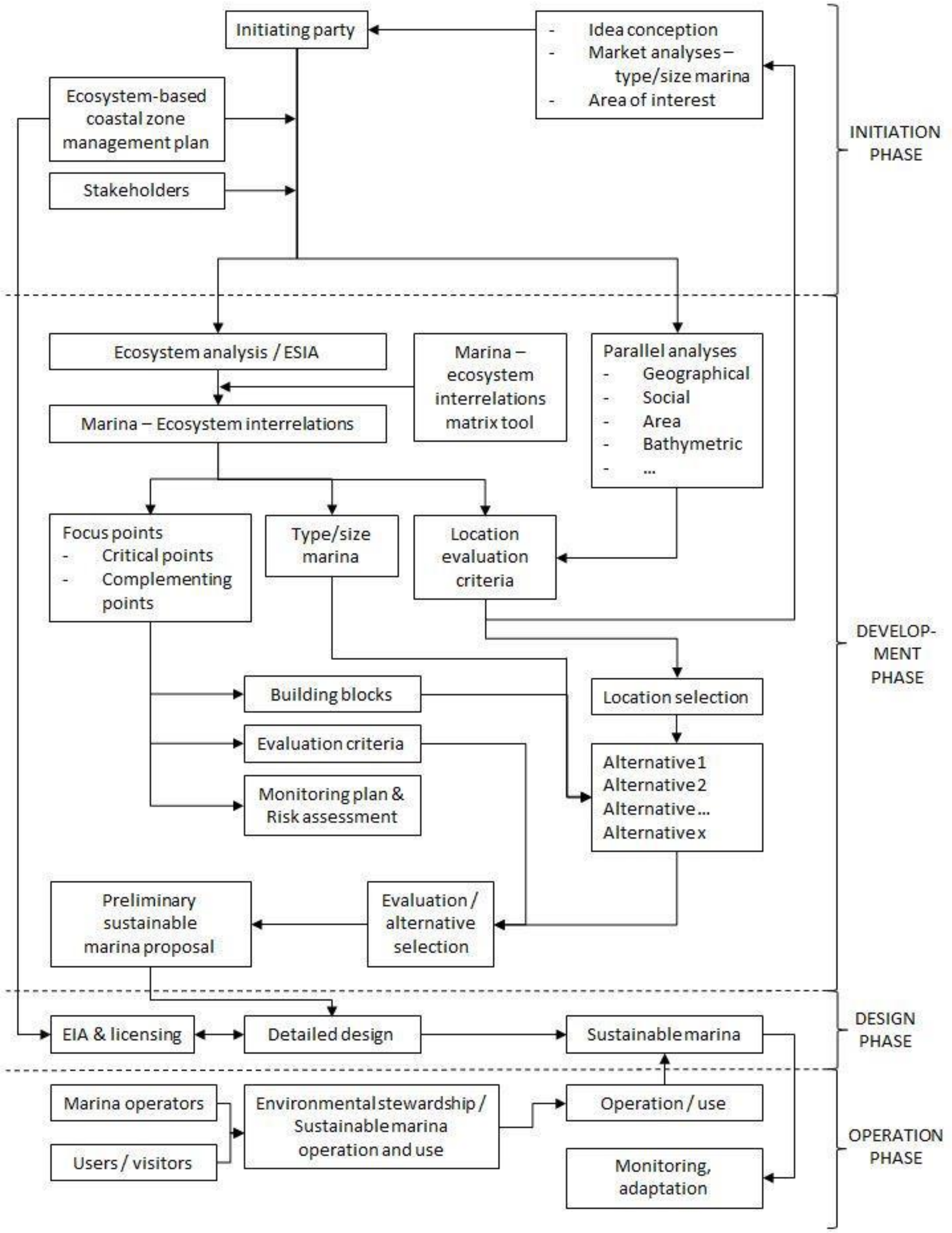


Figure 68: Ecosystem-based marine development (G. de Boer, 2016)

APPENDIX B : PLANNING PROCEDURE THORESEN

The planning process as used by the author described in section 3.2 is based on the basic planning procedure as described by Thoresen (2014) and is shown below.

a. Resolution by the port authority to start planning
b. Selection of the consulting engineering
c. Scope of work:
    - Introduction
    - Background
    - Scope of project
    - Basic data
d. Registration of users:
    - Public
    - Private
e. Recording of user's needs
    - Types of port and berth structures
    - Traffic statistics
    - Types and specification of ships
    - Coastal areas and maritime conditions
    - Growth factors
f. Impact study
g. Site evaluation
    - Existing areas
    - Potential areas
    - Natural conditions
    - Relationship with neighbors
h. Layout plan
i. Economic analysis
j. Work schedule

Selection of the consulting engineering, scope of work, registration of users, recording of user's needs, impact study, site evaluation and a lay-out plan are phases which are carried out by the author. An economic analysis and a work schedule are not included in this research.

APPENDIX C : STAKEHOLDER CONSULTATIONS

In-text references to interviewees will refer to the number as assigned in column 1 Table 42.

Table 42: Overview of stakeholder consultations

#	Organization	Occupancy	Method	Date
1	National Engineering & Planning Services (NEPS)	Senior Engineer	Interview	19-10-17
2	Myanmar Maritime University (MMU)	Lecturers	Interview	23-10-17
3	Myanmar Engineering Council (MEC)	Chairman/former rector	Interview	27-10-17
4	Myanmar Industrial Port (MIP)	Chief Financial Officer	Interview	31-10-17
5	MOTC: Inland Water Transport (IWT)	Director General	Interview	9-11-17
6	International Centre for Environmental Management (ICEM)	Country Director	Meeting	10-11-17
7	Kanaung Legacy Group (KLG)	Founder	Interview	10-11-17
8.	Netherlands Commission for Environmental Assessment (NCEA)	Sr. Technical Secretary	Call	10-11-17
9.	Council for Scientific Industrial Research (CSIR)	Senior Scientist	Call	10-11-17
10.	Arcadis – Dr. J. Beard	Head of Transport Asia	Interview	17-11-17
11.	Myanmar Maritime University (MMU)	Lecturer	Meeting	20-11-17
12.	Myanmar Port Authority (MPA)	Director General	Interview	21-11-17
13.	Department of Marine Administration (DMA)	Director General	Interview	22-11-17
14	Regional Pathein Port Authority	Head Port Officer	Interview	1-12-17
15.	Regional Ministry of Transport Mon State	Chief Minister	Interview	8-12-17
16.	Arcadis – A. Dekker	Senior Advisor	Validation	26-2-18
17.	Arcadis – C. Beenhakker	Senior Advisor	Validation	27-2-18
18.	Arcadis – J. de Groot	Project manager	Validation	27-2-18
19.	TU Delft – Prof. B. van Wee	Professor TIL	Validation	1-3-18
20.	Deltares – W. de Boer	Researcher	Validation	15-3-18

APPENDIX D : COMPLETE STAKEHOLDER LIST

The list of relevant stakeholders is based on 1. ''The survey program for the National Transport Development plan in the Republic of the Union of Myanmar (JICA, 2017)'', 2. the ''Delta Atlas (IADS team, 2017), and 3. The websites from the ministries. The ministries responsible for the development of ports are the Ministry of Transport and Communication (MOTC), and the Ministry of Construction (MOC). The relevant departments and organizations under the MOTC and the MOC are described in the below tables.

Ministry of Transport and Communications:

Departments (a.o.)	**Tasks, responsibilities, activities**
Department of Marine Administration (DMA)	The DMA is composed of nine subdivisions. Key functions are: conform national ships to safety standards, develop human resources, optimize utilization of man-power in the maritime sector, save lives and protect the marine environment. (3.)
Department of Meteorology and Hydrology (DMH)	The main objectives of DMH are: taking precautionary measures of natural disasters. Promoting safety, comfort, efficiency and regularity of air, land, sea and inland water transportation. Sustainable development of natural resources. Promote agricultural and food production. Ensure efficient operation, planning and development of activities in nature. (3.)
Directorate of Water Resources and Improvement of River Systems (DWIR)	The DWIR aims to: conserve and protect the water resources and rivers systems for beneficial utilization by the public, smoothen ensure safety of waterway navigation, contribute to the development of economy through improving water resources, protect environmental impact. Besides, they support environmental protection and sustainable production of natural resources. (3.)
Myanmar Port Authority (MPA)	Department of the MOTC which has the responsibility to regulate and administer the existing coastal ports of Myanmar as well as the coastal port developments, and to provide required services (loading, discharging, storage of cargo, receipt and delivery of cargo) for vessels calling to Myanmar. (3.)
Inland Water Transport (IWT)	The department of IWT has been operating the services of passengers and cargo transportation for the regions with navigable waterways such as the Ayeyarwady, Chindwin, Thanlwin, but also for Delta regions and Rakhine state. IWT aims at smooth and secure transportation in Myanmar. (3.)

Other relevant ministries & departments:

Ministry	**Tasks, responsibilities, activities**
Ministry of Natural Resources and Environmental Conservation (MONREC)	Takes care of implementation of national environment policies, laws and rules: planning and action plans for the integration of environmental considerations into the national sustainable development process, and wildlife protection.
Ministry of Construction (MOC)	The Ministry of Construction is responsible for the country's construction and maintenance of infrastructure, including roads and bridges.
Ministry of Planning and Finance (MOPF)	The ministry of planning and finance is divided into the ministry of finance and the ministry of national planning and economic development. The ministry of finance has been formulating and implementing effective monetary and financial policies in order to meet political, economic, social and other development objectives laid down by state.
Myanmar Oil & Gas Enterprise (MOGE)	MOGE is a department of the Ministry of Electricity and Energy. It is a publicly owned oil and gas company, established in 1963.

Private parties

Organization	Tasks, responsibilities, activities
Myanmar Industrial Port	National, privately-owned port of Yangon. MIP's main business is the handling of containers and other port services on an international level. 12 Shipping lines are calling to MIP currently. MIP would like to expand their own port activities in Yangon.
National Engineering & Planning Services	NEPS is a local engineering & consultancy firm and a consortium partner of Arcadis, focusing on: irrigation, drainage, flood control, hydraulic structures, hydropower, roads and rural infrastructures, river training, surveying and landscaping.
Maersk shipping lines	Maersk Line is the world's largest container shipping company which moves 12 million containers every year everywhere around the world. Maersk operates shipping lines between Yangon and Singapore.
Myint & Associates Ltd.	Myint & Associates Co. Ltd. Is the first privately owned Myanmar company to conduct business as a service contractor in the oil & gas sector of Myanmar since 1989.
Kanaung Legacy Group	Kanaung Legacy Group is a technical trading company active in Myanmar. Kanaung is specialized in representing and supporting partners/suppliers in the Myanmar market with a focus on sales of technical equipment, engineering and installations in the Maritime and Aviation sector.

Remaining stakeholders

Organization	Tasks, responsibilities, activities
World Bank	The World Bank Group is on the world's largest sources of funding and knowledge for developing countries. Its five institutions share a commitment to reducing poverty, increasing shared prosperity, and promoting sustainable development
Myanmar Fuel & Oil Importers and Distributors Association	This umbrella organization represents the interests of all private and public stakeholders in the oil and gas sector.
Myanmar Maritime University (MMU)	MMU is one of the most selective universities in Myanmar, and aims at contributing towards modernization and development of the state by maritime industry, and to nurture ethical, skillful and reputable experts.
Myanmar Engineering Council (MEC)	MEC aims at future success driven by qualified Myanmar Engineers and (graduate) technicians. Besides, upholding and upgrading the dignity, ethics and quality of the Myanmar citizen engineers, and exploring research and development activities by which the natural and human resources may be beneficially applied with least impact on the environment.
Myanmar International Freight Forwarders Association (MIFFA)	Supporting and assisting in the successful and smooth performance of international freight forwarding services, promoting international freight forwarding activities, and developing and expanding freight forwarding.

APPENDIX E : CURRENT DEEP SEA PORT DEVELOPMENTS

This section elaborates upon the most important information with respect to current deep sea port developments in Myanmar. These developments can be found in chapter 4.

Yangon

Yangon International Port (YIP) is different from other deep sea port developments, because it is not a new project but several small projects focusing on expanding or efficiency are being implemented. Yangon International Port is the main international port of Myanmar, and handles 90% of all cargo in the country (CFO MIP, personal communication, 31-10-2017). Different private port operators operate next to each other, and all of them are in a process of expanding or improve efficiency of the cargo handling. Yangon International Port is located 32 km upstream of Yangon river, at the southern riverbanks of Yangon. The below figures show the exact location of Yangon International Port.

According to JICA (2014), the future development plan of Yangon Main Port can be summarized as follows:

- Introduction of private funds by constructing joint ventures with Myanmar Port Authority
- Upgrading and renovation of existing port terminals
- Utilization of the water front area for recreational and commercial use

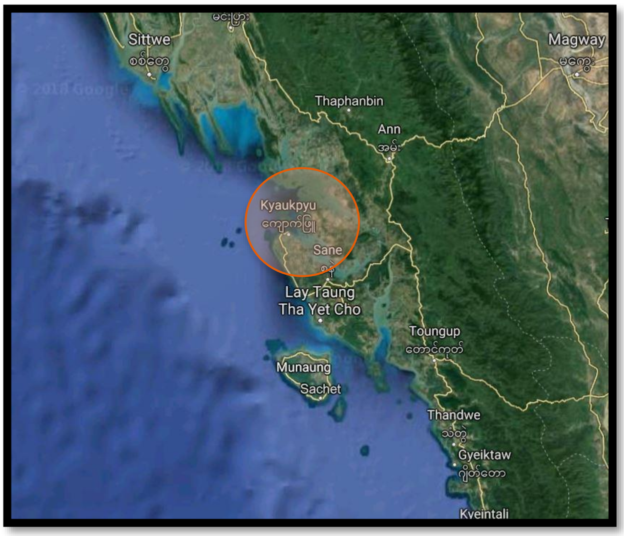
International cargo will be handled at existing port facilities (Asia World Terminal, Myanmar Industrial Port, Sule Multi-purpose terminal, Bo Aung Kyaw terminal), however due to limited land availability expansion of these facilities is limited. Container cargo which cannot be handled at Yangon Port will be handled at Thilawa port, which has large land availability and larger water depths.

Proposed deep sea port locations:

- JICA proposed a deep sea port location 35 km off the left bank of Yangon river mouth (JICA, 2014).
- According to interviewee 3 (27-10-2017), Japan is proposing a deep sea port at the eastern side of the estuary, however sedimentation problems occur over here, and interviewee 3 proposes an offshore port.
- Interviewee 7 (10-11-2017) agrees with interviewee 3 about a proposed location at the eastern part of the river mouth, of which feasibility is studied by RHDHV. This project requires a highway connection with Yangon and Thilawa area.

Kyaukpyu

Kyaukpyu is located in the north of Rambree Island, Kyauk Phyu District, in Rakhine State. The Kyauk Phyu deep sea port plan is being implemented in Maday Island, which is located in the east of Kyauk Phyu city. The development of Kyauk Phyu deep sea port started with the development of a crude oil pipeline from Sittwe in Myanmar to the Kunming Refinery in China, in order to receive supplies faster from the Middle East and Africa. Operations on the line started in 2011, and the line was completed in 2014. Originally it was scheduled to start operating the line in 2014 as well, however after years of delay, and lowering of the transit fees by Myanmar, the line started operating in 2017 (Bloomberg, 2017). The below figures show the exact location of Kyaukpyu port.



According to interviewee 3 (2017), Kyauk Phyu is well suited for Post-Panamax vessels because of the large natural depths over 13.5 meter. A disadvantage is the lack of hinterland connections because of the mountainous hinterland, which will cause large investments in roads and waterways towards the main market in Yangon. Transshipment to Yangon may be possible, and Kyauk Phyu seems like an ideal location because of the large natural water depths and an already available approach channel. A big disadvantage however, is the political conflict situation in the area of Kyauk Phyu. These statements are confirmed by JICA (2017), who state that Kyaukpyu is well-suited for accommodating VLCC's because of large water depts, however land-transport access is underdeveloped because of the Arakan Mountain range with steep slopes. Because of long and low quality transportation towards the key hinterland, there is no rationale for developing Kyaukpyu as deep sea port.

As stated by the Dutch Maritime Network (2016), CITIC won two contracts for development of the SEZ and a deep sea port. A consortium led by China's CITIC Group has proposed taking a 70-85 percent stake in the $7.3 billion deep sea port. This proposed Chinese stake is substantially larger than the 50/50 joint venture proposed by Myanmar late last year. Kyaukpyu is important for China, as it is part of its ''One Belt, One Road'' infrastructure to connect China with Asia and beyond. Besides, it is the entry point for a Chinese oil and gas pipeline which gives an alternative route for energy imports from the Middle East that avoids the Malacca straits (Reuters, 2017).

Pathein

The river port of Pathein is an important port in the Ayeyarwady region, especially for fisheries. Ambitious plans are made to develop Pathein Industrial City (PIC), a large-scale development area which concerns industries, port facilities and residential areas. In 2012, feasibility studies were carried out and PIC received support from the regional government. Then in 2014, land acquisition started and the first design report was finalized. Environmental Impact Assessments and Social Impact Assessments were finished in 2015 and a permit from the Myanmar Investment Company (MIC) was obtained in 2016. After completion of PIC, the city also has plans for deep sea port development in Nga Yoke Kaung area, located south west at a distance of 102 km from PIC (Ayeyarwaddy Development Public Co. LTD, 2017). This will be necessary to enable larger ships to enter the region in the future. The deep sea port at Nga Yoke Kaung area will serve as a transshipment port to serve PIC and YIP.

Besides the proposed deep sea port location at Nga Yoke Bay, another location 60 km to the north at Danson Bay is proposed. This Bay has got larger water depths, but the hinterland connectivity is worse than at Nga Yoke Bay. The exact location of the port will be selected based on considerations in terms of transport, as stated by U Ye Lin from Myanmar Construction and Development Public Co, who are studying feasibility together with the South-Korea based Korea Engineering Consultants Corp (KECC) (Port Technology, 2017).

The feasibility study is expected to be completed soon. If the report findings are positive, the proposal will be submitted to the regional government. Only when the State government and the regional government agree, the proposal will go ahead. This means that the implementation phase may start in 2020 (Htwe, 2017)

Thilawa

MITT is a multi-purpose container terminal located at Thilawa near the mouth of the Yangon River. MITT has five berths capable of handling a wide variety of cargo. Almost all of the 37 plots of Thilawa area have been sold to private companies and the development and operation of some areas has been commenced. Thilawa can be seen as the expansion of Yangon Port, born out of space limitations near Yangon. Container terminals, Ro/Ro terminals, dry bulk terminals and general cargo terminals are planned. A big disadvantage is the bad road connection with Yangon. However, this location offers opportunities for barging of cargo to Yangon.

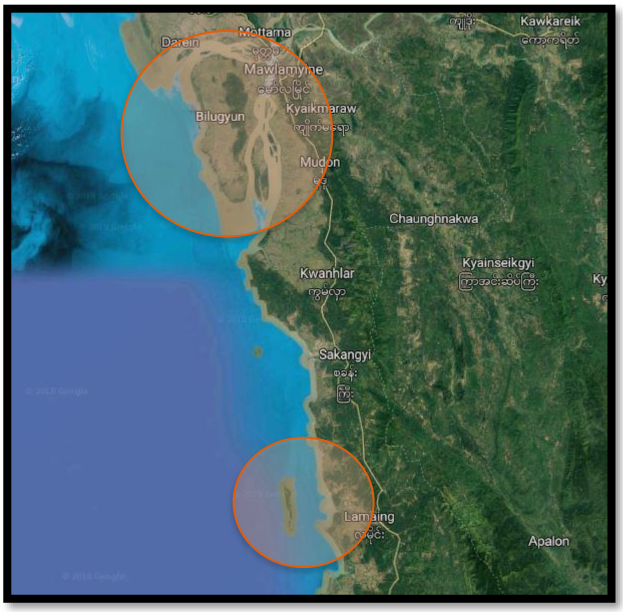
The need for Thilawa area is explained by by JICA (2014): to support the future economic development of Myanmar, key roles will be played by Yangon Port in Yangon city and Thilawa Port, which both have Yangon (the largest city in Myanmar), as the hinterland. The two ports have limitations in channel depth. However, considering the proximity to the largest city as well as the development of a SEZ, they are expected for the time being to function as the gateway ports supporting the economic development of Myanmar.

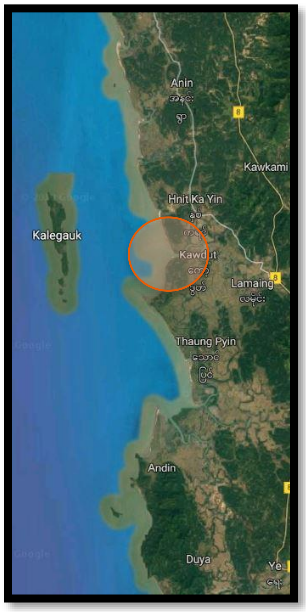
Role sharing between Yangon International Port and Thilawa Port

- No additional large terminal developments at Yangon International Port should be executed, but the existing and planned port facilities for international trade cargo should be utilized as extensively as possible
- The remaining water front areas should be used for facilities which directly benefit the lives of citizen such as passenger terminals, domestic transport terminals, promenades, shopping centers and office buildings
- Port facilities which will handle future increasing international trade cargo should be constructed in Thilawa area port
- Promotion of a new road network development connecting Thilawa area and the city and the hinterland should be contemplated in order to improve the existing poor road network
- The north part of Thilawa area should be utilized for facility development needed after the completion of the whole planned facilities at Thilawa area

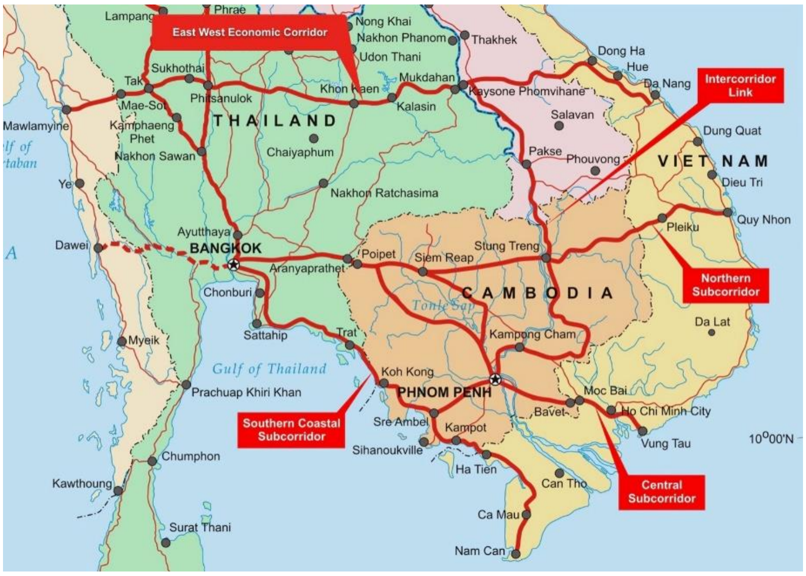
Mawlamyine/Kalegauk

Mawlamyine is the capital of Mon State and possesses a shallow river port in the city center. It is a proposed candidate for the new deep sea port and it can function as a gateway for the East West Economic Corridor (EWEC) in Myanmar. The existing city center port is only 5 meters deep, and therefore studies have been undertaken to search for new deep sea port sites. During a stakeholder meeting at the Regional Government of Mon State, with the Regional Minister of Transport and Communications, it became clear that several locations are studied, however a location near Lamaing at the Kalegauk Island is the most promising one.



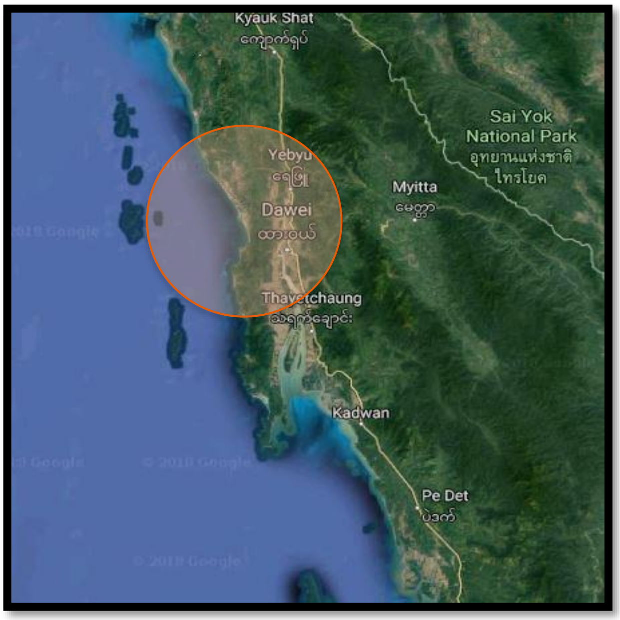


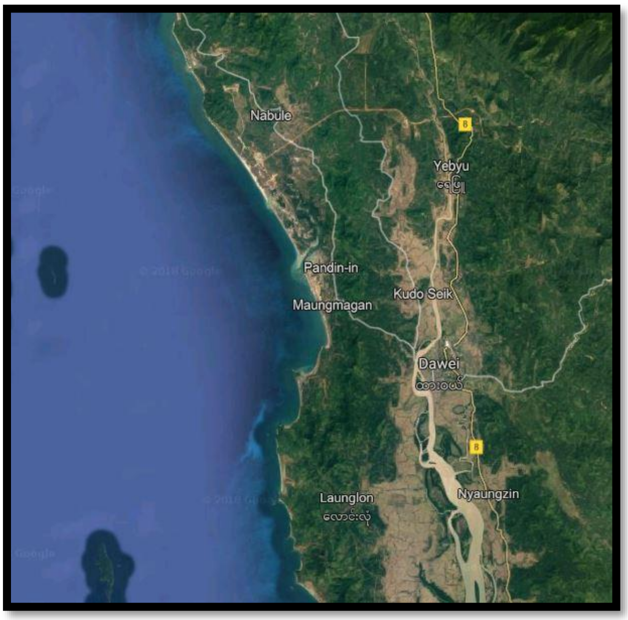
The below figure shows the East West Economic Corridor. This road corridor is under development and links Myanmar with Thailand, Cambodia, Laos, and Vietnam by ending the corridor at Da Nang port. This offers opportunities for Myanmar in serving as a transshipment hub and provide alternatives for the congested Street of Malacca.



Dawei

Dawei Special Economic Zone is developed by the Italian-Thai Development (ITD) Public Company Ltd. It includes a deep sea port with a 20 m deep access channel and berths with depths of -12 to -16 m. The total planned number of berths is 58. The port is planned as an industrial estate with a power plant and water supply, and the SEZ connected by road and rail. This port and related facilities are expected to be the gateway of the Southern Economic Corridor of the Greater Mekong Sub-region (GMS) (JICA, 2017). Dawei is located 630 km South-East from Yangon and 300 km West from Bangkok.



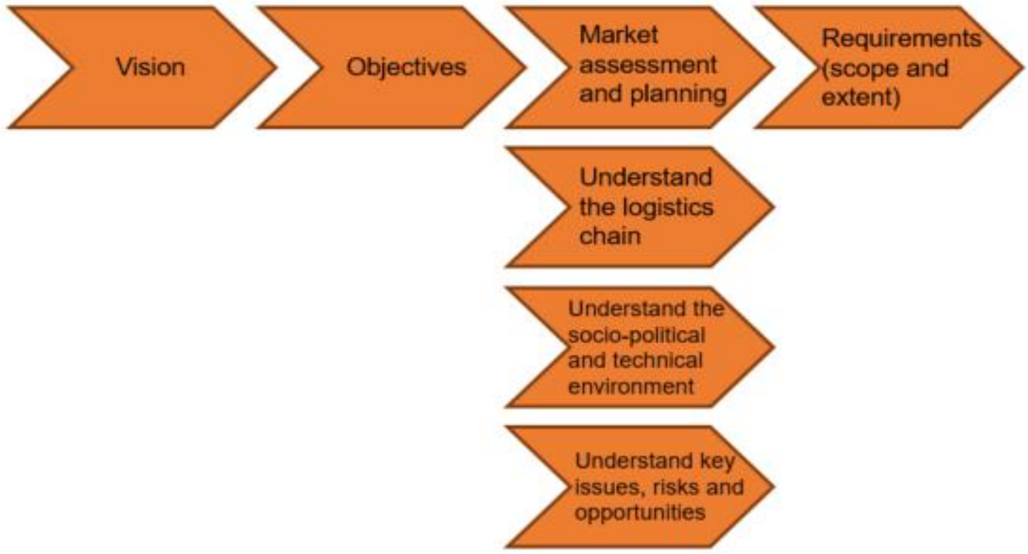


The development plans for Dawei SEZ rank among the largest industrial zones in the world. It has obtained the status of SEZ for inviting financing parties, especially for the development of heavy industries (refineries, LNG plants, chemical complexes, blast furnaces, etc.) and for light industries in 2008. This is based on a bilateral agreement between the governments of Myanmar and Thailand. The development initiative was from a private developer from Thailand. Until now, and from 2010, the progress of developments stalled due to financial problems of the private industrial area developer. Japan assists with financing, and since last year, developments get slowly back on track (JICA, 2017).

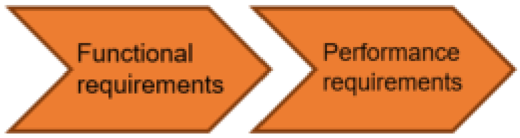
APPENDIX F : PIANC WORKING GROUP 185

Below six steps describe in detail the site selection process of the PIANC working group 185. These six steps and the site selection process can be found in section 5.3.2.

Step 1: Identifying the vision, strategic objectives and requirements

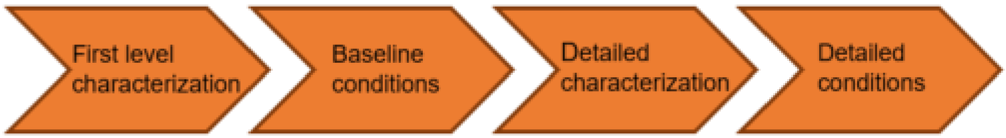


Step 2: Setting the functional and performance requirements

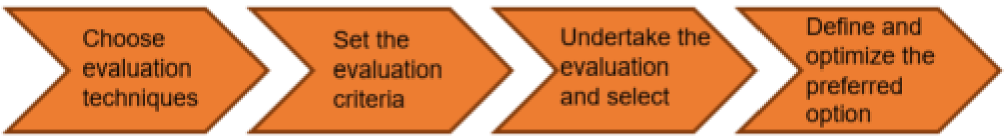


Step 3: Outlining the spatial needs

Step 4: Identification and characterization of potential sites



Step 5: Evaluating and screening potential options



Step 6: Planning the management, permitting and procurement

APPENDIX G : MCA DESCRIPTIONS

In order to provide an indication of the list of different MCA's, and to provide a basis for choosing the right methods, this appendix provides an overview of 29 MCA methods (Guitouni & Jean-Marc, 1997). Motivation for the MCA method used in this research can be found in section 5.4.1.

MCAP	References	Description of the MCAP
Elementary methods		
Weighted sum	See [21,40,54]	The global performance of an alternative is computed as the weighted sum of its evaluations along each criterion. The global performance is used to make a choice among all the alternatives
Lexicographic method	See [40,79]	Based on the logic that in some DMS a single criterion seems to predominate. The procedure consists in comparing all the alternatives with respect to the important criterion, and proceed with the next one until only one alternative is left
Conjunctive method	See [40,20]	An alternative which does not meet the minimal acceptable level for all criteria is rejected. The minimal acceptable levels for each criterion are used to screen out unacceptable alternatives
Disjunctive method	See [40,20]	An alternative is selected on the basis of its extreme score on any one criterion. Desirable levels for each attribute are used to select alternatives which equal or exceed those levels on any criterion
Maximin method	See [40]	The overall performance of an alternative is determined by its weakest or poorest evaluation
Single synthesizing criterion		
TOPSIS (technique for order by similarity to ideal solution)	See [40]	The chosen alternative should have the profile which is the nearest (distance) to the ideal solution and farthest from the negative-ideal solution
MAVT (multi-attribute value theory)	See [43,45]	Aggregation of the values obtained by assessing partial value functions on each criterion to establish a global value function *V*. Under some conditions, such *V* can be obtained in an additive, multiplicative or mixed manner
UTA (utility theory additive)	See [41]	Estimate the value functions on each criterion using ordinal regression. The global value function is obtained in an additive manner
SMART (simple multi-attribute rating technique)	See [26,27,62]	Simple way to implement the multiattribute utility theory by using the weighted linear averages, which give an extremely close approximations to utility functions. There are many improvements like SMARTS [28], SMARTER [8]
MAUT (multi-attribute utility theory)	See [19,43,93]	Aggregation of the values obtained by assessing partial utility functions on each criterion to establish a global utility function *U*. Under some conditions, *U* can be obtained in an additive, multiplicative or distributional manner
AHP (analytic hierarchy process)	See [81,82]	Converting subjective assessments of relative importance into a set of weights. This technique applies the decomposition, the comparative judgments on comparative elements and measures of relative importance through pairwise comparison matrices which are recombined into an overall rating of alternatives
EVAMIX	See [94]	Two dominance indexes are calculated: one for ordinal evaluations and the other one for cardinal evaluations. The combination of these two indexes leads to a measure of the dominance between each pair of alternatives
Fuzzy weighted sum	See [4,23,46]	These procedures use α-cut technique. The α level sets are used to derive fuzzy utilities based on the simple additive weighted method
Fuzzy maximin	See [10,98]	This procedure is based on the same principle as the standard maximin procedure. The evaluations of the alternatives are fuzzy numbers
Outranking methods		
ELECTRE I	See [70]	The concept of outranking relationship is used. The procedure seeks to reduce the size of nondominated set of alternatives (kernel). The idea is that an alternative can be eliminated if it is dominated by other alternatives to a specific degree. The procedure is the first one to seek to aggregate the preferences instead of the performances

MCAP	References	Description of the MCAP
ELECTRE IS	See [79]	This procedure is exactly the same as ELECTRE I, but it introduces the indifference threshold
ELECTRE II	See [78]	ELECTRE II use two outranking relations (strong and weak)
ELECTRE III	See [71]	The outranking is expressed through a credibility index
ELECTRE IV	See [80]	This procedure is like ELECTRE III but did not use weights
ELECTRE TRI	See [79]	This procedure is like ELECTRE III and use the conjunctive and disjunctive techniques to affect the alternatives to the different categories (ordered)
PROMETHEE I	See [18]	PROMETHEE I is based on the same principles as ELECTRE and introduces six function to describe the DM preferences along each criterion. This procedure provides a partial order of the alternatives using entering and leaving flows
PROMETHEE II	See [17]	PROMETHEE II is based on the same principles as PROMETHEE I. This procedure provides a total preorder of the alternatives using an aggregation of the entering and leaving flows
MELCHIOR	See [50]	MELCHIOR is an extension of ELECTRE IV
ORESTE	See [69]	This procedure needs only ordinal evaluations of the alternatives and the ranking of the criteria in term of importance
REGIME	See [38]	A pairwise comparison matrix is built using +1 if there is dominance, 0 if the two alternatives are equivalent and –1 for the negative-dominance. The aggregation of these weighed scores provides a total preorder of the alternatives
NAIADE (novel approach to imprecise assessment and decision environments)	See [60]	This procedure uses a distance semantics operators to assess the pairwise comparisons among alternatives. The fuzzy evaluation are transformed in probabilities distributions and as PROMETHEE, this procedure compute entering and leaving flows
Mixed methods		
QUALIFLEX	See [64]	This procedure uses a successive mutations to provide a ranking of the alternative corroborating with the ordinal information
Fuzzy conjunctive/ disjunctive method	See [24]	When data are fuzzy, the match between values and standard levels provided by the DM and the evaluations becomes vague and a matter of degree. The degree of matching is computed using the possibility measure and the necessity measure. The alternatives with the highest degree of matching are considered the best
Martel and Zaras method	See [56,57]	This procedure uses the stochastic dominance to make pairwise comparison. These comparison are used as partial preferences and an outranking relation is built based on a concordance index and discordance index

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APPENDIX H : MCA COMPARISONS

This appendix shows comparison of different MCDA methods based on seven criteria (Guitouni & Jean-Marc, 1997). Again, motivation for the MCA method used in this research can be found in section 5.4.1.

1. G1: determination of stakeholders of the decision process
2. G2: consider the decision makers (DM) ‘cognition’ or his/her way of thinking
3. G3: determine the decision problematic pursued by the decision maker
4. G4: choose the multi-criterion aggregation procedure that can handle the information input
5. G5: determine the compensation degree, if DM refuses compensation, many MCAP fall off
6. G6: the fundamental hypothesis of the method should be met
7. G7: software packages available for MCDA

Comparisons of MCDA methods on the basis of the G2, G3 and G4 guidelines (case of the elementary and single synthesizing criterion methods)

Method	Guideline									
	G2				G3	G4				
	Pref. eluc. mode	Moment	Pref. struct.	Order	Dec. probl.	Kind of information			Information features	
						Ord.	Card.	Mix.	Deter.	Non deter.
Elementary methods										
Weighted sum	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Total preorder	α		✓		✓	
Lexicographic method	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Total preorder	α	✓	✓	✓	✓	
Conjunctive method	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Filtration	n/a [a]	✓	✓	✓	✓	
Disjunctive method	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Filtration	n/a	✓	✓	✓	✓	
Maximin method	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Total preorder	α	✓	✓		✓	
Single synthesizing criterion										
Fuzzy weighted sum	Straightforward (*direct rating*)	a priori	{**P**, **Q**, **I**}	Semiorder	α	✓	✓	✓		✓
TOPSIS	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Total preorder	α		✓		✓	
MAVT	Tradeoffs	a priori	{**P**, **I**}	Total preorder	α		✓		✓	
UTA	Tradeoffs	a priori	{**P**, **I**}	Total preorder	α	✓			✓	
SMART	Tradeoffs & rating	a priori	{**P**, **I**}	Total preorder	α		✓		✓	
MAUT	Tradeoffs & lotteries	a priori	{**P**, **I**}	Total preorder	α		✓			✓
AHP	Pairwise comparison	a priori	{**P**, **I**}	Total preorder	α, γ		✓		✓	✓
EVAMIX	Straightforward (*direct rating*)	a priori	{**P**, **I**}	Total preorder	α, γ	✓	✓	✓	✓	
Fuzzy maximin	Straightforward (*direct rating*)	a priori	{**P**, **Q**, **I**}	Semiorder	α	✓	✓		✓	✓

[a] n/a: Not applicable.

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Comparisons of MCDA methods on the basis of the G2, G3 and G4 guidelines (case of the outranking and mixed methods)

Method	Guideline									
	G2				G3	G4				
	Pref. eluc. mode	Moment	Pref. struct.	Order	Dec. probl.	Kind of information			Information features	
						Ord.	Card.	Mix.	Deter.	Non deter.
Outranking methods										
ELECTRE I	Pairwise comparison	a priori	{**S**, **R**}	Core	α	✓	✓	✓	✓	
ELECTRE II	Pairwise comparison	a priori	{**S**[F], **S**[f], **R**}	Partial semiorder	γ	✓	✓	✓	✓	
ELECTRE III	Pairwise comparison	a priori	Valued {**S**, **R**}	Partial semiorder	γ	✓	✓	✓	✓	
ELECTRE IV	Pairwise comparison	a priori	{**S**[1], **S**[2], **S**[3], **S**[4], **S**[5], **R**}	Partial preorder	γ	✓	✓	✓	✓	
ELECTRE IS	Pairwise comparison	a priori	{**S**, **R**}	Partial semiorder	α	✓	✓	✓	✓	
ELECTRE TRI	Pairwise comparison	a priori	{**S**, **R**}	Partial interval order	β	✓	✓	✓	✓	
PROMETHEE I	Pairwise comparison	a priori	Valued {**P**, **I**, **R**}	Partial semiorder	γ	✓	✓	✓	✓	
PROMETHEE II	Pairwise comparison	a priori	Valued {**P**, **I**}	Total preorder	γ	✓	✓	✓	✓	
MELCHIOR	Pairwise comparison	a priori	Valued {**S**, **R**}	Partial semiorder	γ	✓			✓	
ORESTE	Pairwise comparison	a priori	Valued {**P**, **I**, **R**}	Partial semiorder	γ	✓			✓	
REGIME	Pairwise comparison	a priori	{**S**, **R**}	Partial semiorder	γ	✓			✓	
NAIADE	Pairwise comparison	a priori	{**S**, **R**}	Total or partial semiorder	γ	✓	✓	✓	✓	✓
Mixed methods										
QUALIFLEX	Pairwise comparison	a priori	{S, R}	Total semiorder	γ	✓			✓	
Fuzzy conjunctive/ disjunctive method	Straightforward	a priori	{P, Q, I}	n/a [a]	α, β			✓		✓
Martel and Zaras method	Pairwise comparison	a priori	{S, R}	Partial semiorder	γ	✓	✓	✓		✓

[a] n/a: Not applicable.

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Comparisons of MCDA methods on the basis of the G5, G6 and G7 guidelines (case of the elementary and single synthesizing criterion methods)

Method	Guideline					
	G5			G6		G7
	Discrimination power of the criteria	Compensation	Information Inter-criteria	Hypothesis [a]	MCAP treatment	Software package
Elementary methods						
Weighted sum	Absolute	Totally	Total and explicit importance coeff.	ind., com., inv., tran., dom.	Algebraic sum	
Lexicographic method	Absolute	Non	n/a [b]	ind., inv., tran., dom.	Cutting planes	
Conjunctive method	Absolute	Non	n/a	ind., inv., tran., dom.	Thresholds	
Disjunctive method	Absolute	Non	n/a	ind., inv., tran., dom.	Thresholds	
Maximin method	Absolute	Non	n/a	ind., inv., tran., dom.	Max and min operators	
Single synthesizing criterion						
Fuzzy weighted sum	non-absolute	Totally	Total and explicit	ind., com., inv., tran., dom.	α-cut and fuzzy arithm.	
TOPSIS	Absolute	Totally	Total and explicit	ind., com., inv., tran., dom.	Euclidien distances	
MAVT	Absolute	Partially	Total and explicit	ind., inv., tran., dom.	Value aggregation (sum or mult)	✓
UTA	Absolute	Partially	Indirect	ind., inv., tran., dom.	Value aggregation (sum)	✓
SMART	Absolute	Partially	Total and explicit	ind., com., inv., tran., dom.	Value aggregation (sum)	✓
MAUT	Absolute	Partially	Total and explicit	ind., inv., tran., dom.	Utility aggregation (sum or mult)	✓
AHP	Absolute	Partially	Total and explicit	inner and outer ind., inv., dom.	Eigenvector method	✓
EVAMIX	Absolute	Partially	Total and explicit	ind., com., inv., tran., dom.	Algebraic sum	
Fuzzy maximin	Non-absolute	Non	n/a	ind., com., inv., dom.	Max and min operators	

[a] ind.: Independence, com.: commensurability, inv.: invariance, tran.: transitivity, dom.: dominance.
[b] n/a: Not applicable.

Comparisons of MCDA methods on the basis of the G5, G6 and G7 guidelines (case of the outranking and mixed methods)

Method	Guideline					
	G5			G6		G7
	Discrimination power of the criteria	Compensation	Information Inter-criteria	Hypothesis [a]	MCAP treatment	Software package
Outranking methods						
ELECTRE I	Absolute	Partially	Total and explicit	ind., inv., coal.	Graph theory (core)	✓
ELECTRE II	Absolute	Partially	Total and explicit	ind., inv., coal.	Graph theory (distillation)	
ELECTRE III	Non absolute	Partially	Total and explicit	ind., inv., coal.	Graph theory (distillation)	✓
ELECTRE IV	Non absolute	Partially	n/a [b]	ind., inv., coal.	Graph theory (distillation)	✓
ELECTRE IS	Non absolute	Partially	Total and explicit	ind., inv., coal.	Graph theory (core)	✓
ELECTRE TRI	Non absolute	Partially	Total and explicit	ind., inv., coal.	Disjunctive and conjunctive	✓
PROMETHEE I	Non absolute	Partially	Total and explicit	ind., inv., coal.	Leaving and entering flows	✓
PROMETHEE II	Non absolute	Partially	Total and explicit	ind., inv., coal.	Leaving and entering flows	✓
MELCHIOR	Non absolute	Partially	Total order	ind., inv.	Graph theory (distillation)	
ORESTE	Absolute	Partially	Total preorder	ind., inv., coal.	Graph theory	✓
REGIME	Absolute	Partially	Total order	ind., inv.	Graph theory	✓
NAIADE	Non absolute	Partially	n/a	ind., inv.	Fuzzy arithm and leaving and entering flows	✓
Mixed methods						
QUALIFLEX	Absolute	Partially	Total or partial and explicit	ind., inv.	Concordance analysis	✓
Fuzzy conjunctive/disjunctive method	Absolute	No	n/a	ind., inv., tran., dom.	Possibility and necessity measures	
Martel and Zaras method	Non absolute	Partially	Total and explicit	ind., inv., coal.	Graph theory	

[a] ind.: Independence, com.: commensurability, inv.: invariance, tran.: transitivity, dom.: dominance, coal.: coalition (social choice theory).
[b] n/a: Not applicable.

APPENDIX I : WORKSHOP RESULTS

This appendix presents all results from the workshop on sustainable port development. First general information will be given, afterwards the two interactive sessions are discussed, and finally the results of the individual questionnaire are presented.

ARCADIS Design & Consultancy for natural and built assets — Kingdom of the Netherlands — TU Delft

7 Dec 2017

On behalf of Arcadis, the Embassy of the Netherlands and Delft University of Technology:

Capacity building on ''Deep sea port development opportunities in Myanmar''

- Date: Tuesday the 19th of December 2017
- Time: 9:30 AM – 12:00 AM
- For: Invitees can be found at the bottom of this invitation
- Location: Embassy of the Netherlands, 84 Pan Hlaing Street, San Chaung

Please confirm attendance and number of participants by mail or phone before the 14th of December

Time	Agenda item	By
9:15	Registration of participants	
9:30	Opening remark	Embassy of the Netherlands Ms. Tanya Huizer
9:40	Introduction: objectives, benefits, subjects	Mr. Michel Oosterwegel
9:50	Session 1: Valuation of ecosystem services and discussion: which services are valued most important and what is the impact of port developments on the ecosystem?	All participants
10:30	Coffee break & group photo	
10:45	Presentation of key findings research on deep sea port development	Mr. Michel Oosterwegel
11:00	Session 2: Valuation of site selection criteria by means of pairwise comparison and discussion. Introducing a tool which can be used by all participants in future projects.	All participants
11:45	Short questionnaire	All participants
12:00	Closing remark	Mr. Michel Oosterwegel
12:15	Lunch	All participants

Invitees	Invitees
Myanmar Port Authority	Department of Meteorology and Hydrology
Department of Marine Administration	Directorate of Water Res. & Improvement of River Systems
Inland Water Transport	Department of Fisheries/WorldFish
Ministry of Construction	Myanma Five Star Line
Ministry of Planning of Finance	Myanmar International Freight Forwarders Association
Myanmar Maritime University	AsiaWorld Port Management
Myanmar Oil & Gas Enterprise	Myanmar Industrial Port
Environmental Conservation Department	Parami Energy Group
Ministry of Social Welfare, Relief & Resettlement	Myanmar Engineering Council

E: michel.oosterwegel@arcadis.com E: tanya.huizer@arcadis.com **MM:** +95 94 0171 0186

Figure 69: Official invitation multi-stakeholder workshop

General information

A mix of public and private participants was involved in the multi-stakeholder workshop. The below tables show the abbreviations, organization, description and designation of all participants.

Table 43: Abbreviations of workshop participants

Abbr.	Organization	Description
MMU	Myanmar Maritime University	Public – port/harbor engineering department
DoF	Department of Fishery	Public – MOTC department responsible for fisheries
MIP	Myanmar Industrial Port	Private – private port operator with wharves in Yangon
ACP	Andaman Capital Partners	Private – private investor mainly active in Pathein region
PEG	Parami Energy Group	Private – construction company in energy & infrastructure
MPA	Myanmar Port Authority	Public – MOTC department responsible for seaports
DMA	Department of Marine Administration	Public – MOTC department responsible for shipping
MFSL	Myanmar Five Star Line	Public – national shipping line for maritime transport
IWT	Inland Water Transport	Public – MOTC department responsible for IWT
TWA	The Water Agency	Private – company active in connecting water companies
MOTC	Ministry of Transport & Communic.	Public – ministry responsible for infrastructure and comm.

Table 44: Participants name, designation, and organization

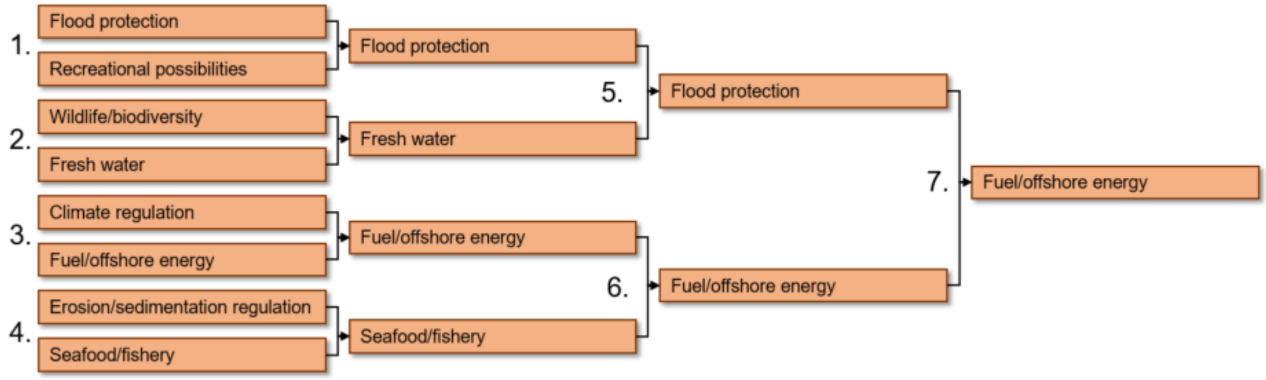
Name	Designation	Department
Ken Tun	Chief Executive Officer	Parami Energy Group
U Soe Win	Head of Services	Parami Energy Services Co. Ltd.
May Khin Chaw	Deputy Director	Department of Meteorology and Hydrology
Julius Kyaw	Deputy Director	Department of Fisheries
Khine Htet Htet Win	Assistant Fisheries Officer	Department of Fisheries
May Soe Aung	Assistant Director	Department of Marine Administration
Aung Htoo	Deputy General Manager	Myanmar Five Star Line
Aung Myat	Manager	Myanmar Five Star Line
Chris 'O Connor	CFO	Myanmar Industrial Port
Hnin Mar	Engineer	Myanmar Industrial Port
Sanda Naing	Professor Port & Harbour dept.	Myanmar Maritime University
Toe Toe Oung	Lecturer Port & Harbour dept.	Myanmar Maritime University
Nyein Zin Latt	Lecturer Port & Harbour dept.	Myanmar Maritime University
Khin Kyu Kyu	Professor Coastal & River dept.	Myanmar Maritime University
U Maung Maung	Deputy General Manager	Inland Water Transport
Khin Khin Myat	Associate	Andaman Capital Partners
Maung Maung Htay	Assistant Engineer	Myanmar Port Authority
U Soe Thein	Chief Engineer	Myanmar Port Authority

Figure 70: Group picture with all participants

Interactive session 1: Ecosystem services valuation

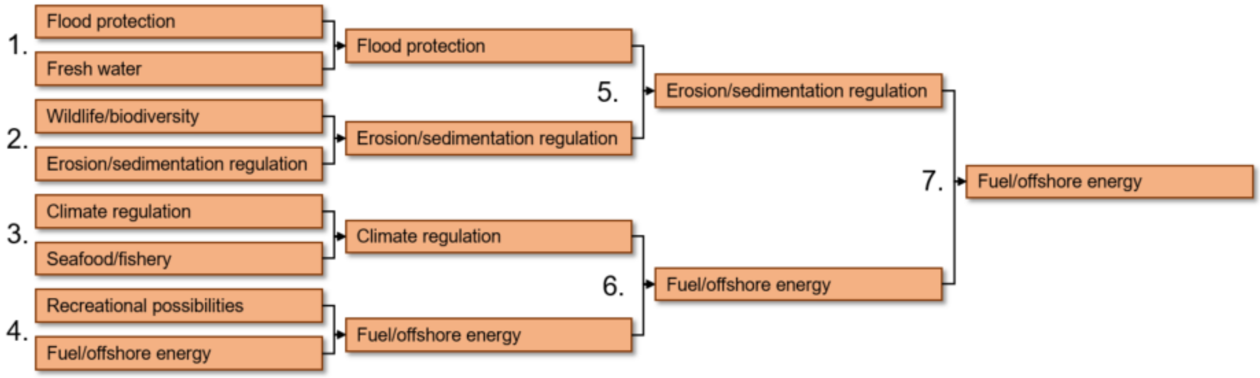
The first interactive group session of the workshop concerned valuation of ecosystem services by stakeholder groups. Reasoning from the four groups is provided. The goal was to start discussion on the importance of ecosystem services for Myanmar (services from the marine/coastal ecosystem from which all people benefit), and to start discussion on the impact of port development on these ecosystem services. The images show the different rounds of comparisons (in a tournament) and which services were given high priority. The enumeration below the tournament images describe motivations provided by the groups.

Group 1



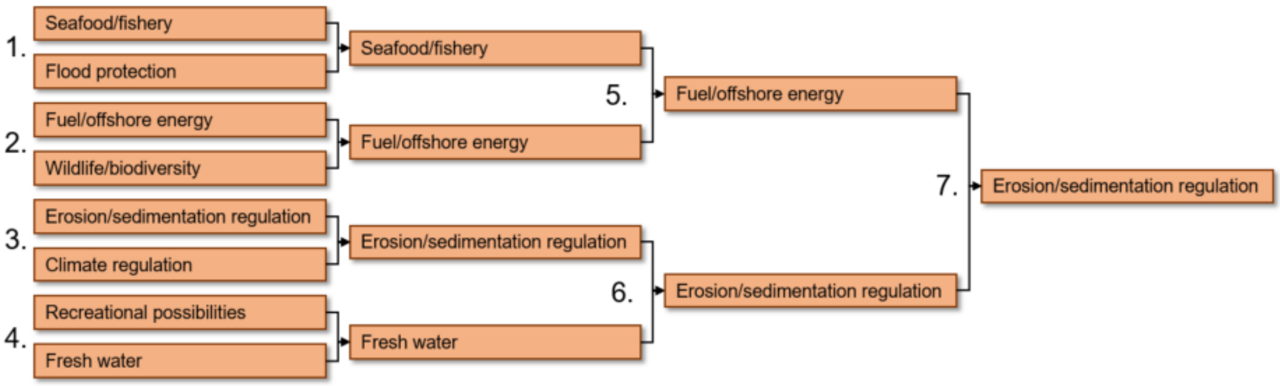
1. Flood protection is important for the protection of families and the economic livelihood
2. Myanmar suffers from inadequate water quality for drinking water
3. Long-term business development of offshore energy should be considered
4. Depends on the chosen location. Yangon/Delta region: erosion, Kyaukpyu/Dawei: fisheries
5. Same reasoning as in 1.
6. Earnings from fuel/offshore energy can be used for coastal development
7. If enough revenues are earned from energy, flood problems can be handled

Group 2



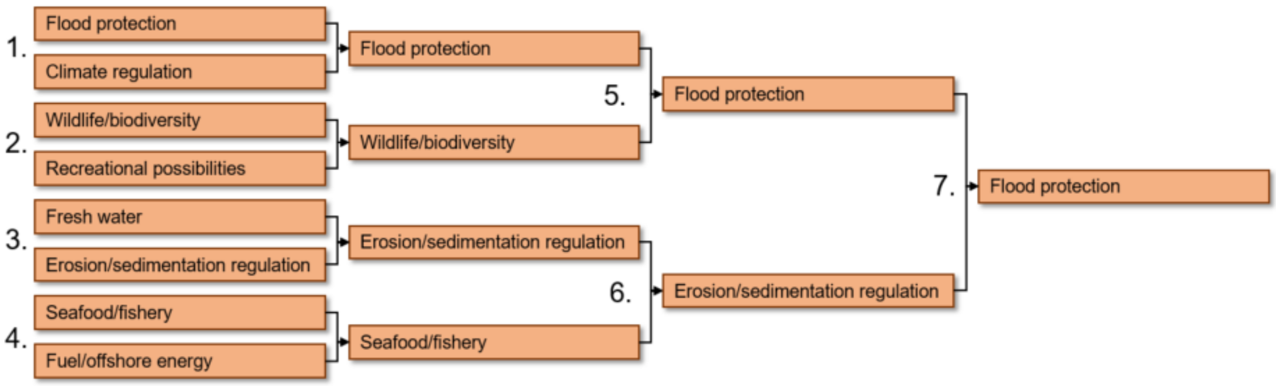
1. Flood protection is important to protect the people and valuable infrastructure
2. Myanmar suffers from large erosion and sedimentation problems
3. Climate regulation also include fisheries
4. Tourism is not located at potential deep sea port locations
5. Erosion and sedimentation problems are difficult to control and part of daily business
6. Fuel/offshore energy yields large benefits for the economy
7. Without fuel/offshore energy, development is impossible. Erosion/sedimentation can be handled.

Group 3



1. Food security more important → pollution of the ecosystem must be controlled
2. Responsible offshore and sustainable energy → coal energy for port operation must be prohibited
3. Improvement of the navigation system leads to more economic development
4. First fresh water security, afterwards recreation → pollution and impact mitigation
5. Sustainable energy protects seafood/marine ecosystem → port policies which prevent impact biodiversity
6. Control erosion by protecting regulations
7. Important for long-term water system → erosion is key for sustainable port development

Group 4



1. Protection of people and cities is more important
2. If wildlife/biodiversity is protected, this will improve wetlands, which will attract tourism
3. Because of the five month rainy monsoon season, fresh water is less important
4. Fuel/offshore energy is important for income, however seafood/fishery is more important for food security

Figure 71: Presentation by MMU on the findings of the first interactive group session

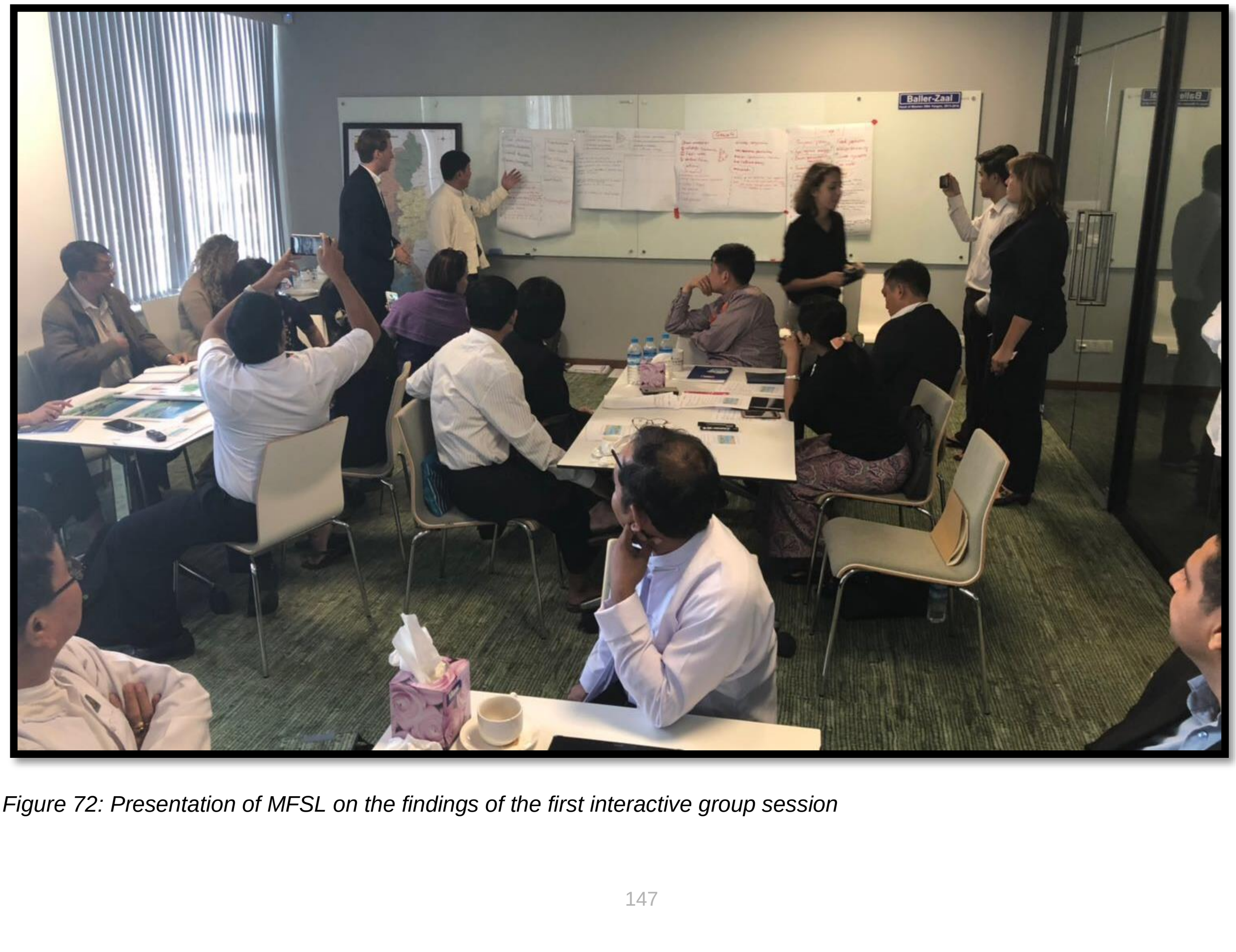


Figure 72: Presentation of MFSL on the findings of the first interactive group session

Interactive session 2: Site selection criteria weighting

The second interactive group session concerned determination of the importance of selection criteria by deriving weight parameters. Determining importance of the selection criteria is done by using a pair-wise comparison. For a pair of selection criteria, stakeholders or a group of users determines subjectively which criterion is more important than the other ones and to what extent. The pairwise comparison contains a standardized procedure to translate this into weights in a non-subjective manner (van der Kleij, Hulscher, & Louters, 2003). The tables below provide the results of the pairwise comparison as conducted during the workshop. The numbers indicate percentages. The columns indicate the stakeholders (last column is the average value) and the rows the selection criteria. In section 6.3.5, these results are clustered and used for the site selection.

	N. Em.	MFSL	MMU	MMU	MMU	IWT	MIP	MIP
Environmental impact	15	5	3	8	7	7	5	14
Social & Political impact	27	4	7	5	**50**	**33**	12	**39**
Economic impact	**38**	25	32	14	9	21	**39**	21
Adaptivity	12	16	9	9	18	12	9	5
Logistics & construction cost	5	**34**	6	**42**	13	10	31	10
Feasibility & schedule	3	16	**43**	22	3	17	4	11

	DMA	DMH	DoF	ACP	MPA	MPA	PEG	Avg.
Environmental impact	7	11	**31**	10	16	6	**27**	11%
Social & Political impact	15	2	19	**29**	**24**	**32**	9	20%
Economic impact	14	**30**	25	10	18	16	17	**22%**
Adaptivity	15	29	8	15	12	5	13	12%
Logistics & construction cost	**28**	2	8	18	19	23	22	18%
Feasibility & schedule	21	26	9	18	11	18	12	16%

Figure 73 shows the original results during the workshop. The results of the pairwise comparison were written down on the whiteboard to show the results and to start discussion on the weight parameters.

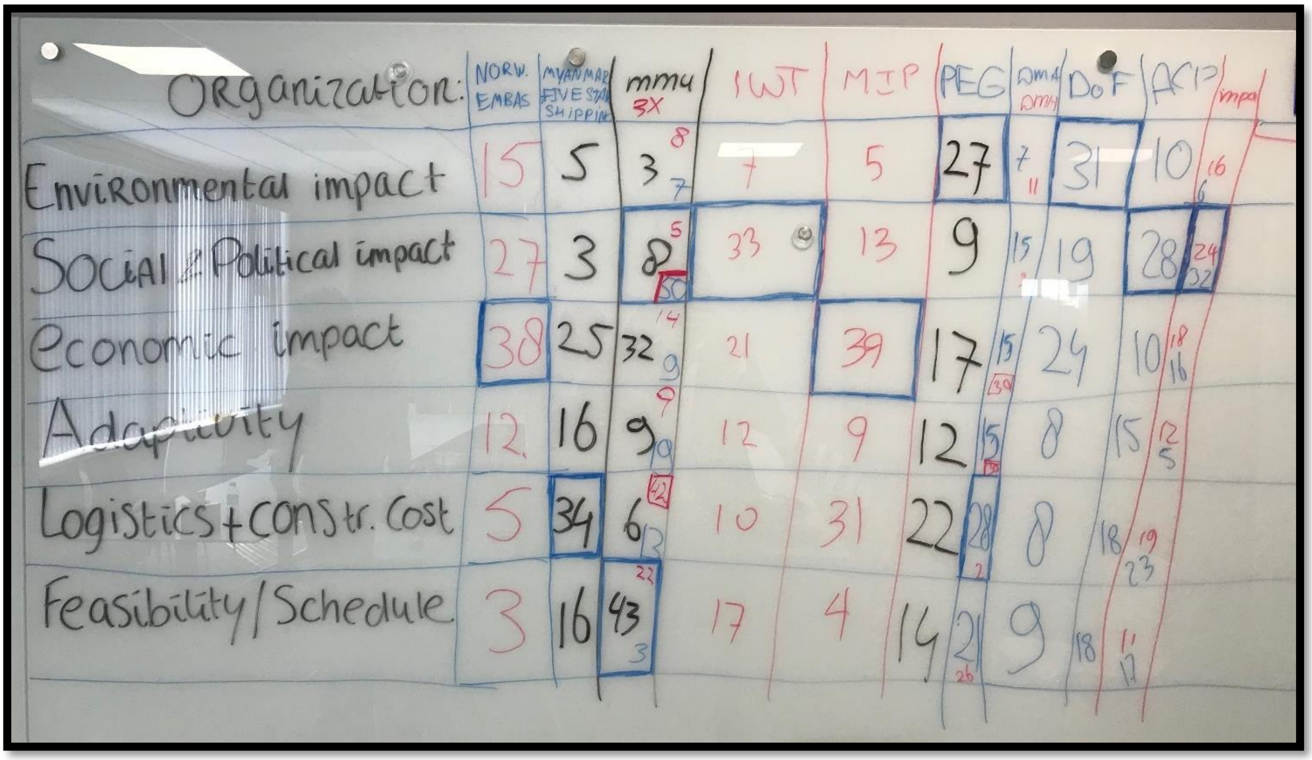


Figure 73: Results of pairwise comparison during the workshop

Questionnaire results

At the end of the workshop, a short individual questionnaire is conducted in order to obtain individual insights and views from the stakeholder, and to validate the selection criteria (see below). It turned out that expressing opinions in a questionnaire was easier than expressing opinions in group discussions. Some of the answers are presented anonymously.

1.) According to your opinion, are these selection criteria useful and important to decide on a location for a deep sea port?

Criterion	Yes	No	%		Criterion	Yes	No	%
Environmental impact					**Adaptivity**			
- Mangrove impact	14	2	74		- Potential for future expanding	18	1	95
- Protected habitat/areas	15	1	**79**		**Logistics/construction cost**			
- Dredging amount	17		90		- Sea/Inland water/Rail/Road	18		95
Social & political impact					- Water depth/shelter	16		84
- Resettlements villages/people	16		**84**		**Feasibility/schedule**			
- Labor availability/workforce	14	1	74		- Timespan for implementation	15	2	79
- Accordance to policy/masterplan	17		90		- Level of complexity	14	2	74
- Tourism impact	9	6	47		- Legislative difficulties	14	2	74
Economic impact								
- Attraction to investors	17		90					
- Fishery impact	13	2	68					
- Impact on economic inequality	14	1	74					
- Sustainable Goals contribution	19		100					

2.) Are the criteria in the above table sufficient to decide on a location for a deep sea port?

Yes: 84%

No: 16%

3.) Which other criterion/criteria should be taken into account for the site selection of deep sea port developments?

MMU: Multi-modal transport, handling equipment

NL. Emb.: Sources of energy, rules & legislation

DMH: Natural disaster prone areas

4.) Which of the ecosystem services below are most important for you personally (which one should experience the least negative impact)? Please rank from 1. (most important) to 8. (least important).

	MMU	MMU	MMU	MIP	MIP	MPA	DMA	MFS	MFS	PEG	A.
Recreational possib.	8	8	8	4	8	8	8	8	3	7	7
Flood protection	2	3	1	5	2	3	2	2	7	4	2
Maintaining wildlife	6	4	4	6	7	7	3	6	6	6	5
Fresh water provision	4	7	5	3	3	2	4	7	5	8	4
Climate regulation	5	6	7	8	6	5	6	5	8	1	6
Fuel/offshore energy	1	2	2	2	1	1	1	1	1	5	1
Seafood provisioning	7	5	6	1	4	6	7	3	4	2	3
Erosion/sedimentation	3	1	3	7	5	4	5	4	2	3	2

5.) Can you give 1 example of the impact (positive or negative) of port development on the ecosystem (services)?

NL. Emb.: port development can improve the local business development (positive), port development can cause loss of natural mangrove forest and fishery productions (negative)

MMU: erosion and sedimentation impact on nearby beaches

MFSL: due to port construction in a certain area, sources of oil & gas can change from one place to another

MIP: proximity of energy sources to a city/port to decrease transportation time/costs

6.) What is according to you the biggest challenge for deep sea port development in Myanmar?

MMU: socio-economic impact & environment

MMU: national policy and <u>budget</u>

MMU: <u>investment</u> & transportation

DoF: technology

NL. Emb.: regulation for deep sea port development & procedures. In addition: long-term plans

PEG: environmental issue is the biggest challenge

MMU: link with world trade route

MPA: export/import volume (trade), hinterland & connectivity between port area & hinterland, lack of infrastructure

DMA: lack of infrastructure, lack of information, import/export trade facilitation

MFSL: biggest challenge is to find <u>investors</u> or developers from outside of Asia because this can have bad impact to some Asia ports

MIP: the <u>overall costs</u> of construction should comply with the total number of containers the DSP will address

IWT: biggest challenge in Myanmar is social and political impact

MFSL: <u>investment cost</u>

7.) What is, according to you, the best location for (further) deep sea port development in Myanmar?

Location	Votes
Sittwe	
Kyauk Phyu	**4**
Pathein Nga Yoke bay	**3**
Pathein Danson bay	
Yangon offshore island	1
Yangon nearshore at river mouth	**4**
Thilawa	**3**
Mawlamyine Bilugyun Island	1
Mawlamyine Kalegauk Island	1
Dawei	**3**
Myeik	

- Mawlamyine is the best location because it is connected with the ASEAN highway (EWEC) project and therefore does not need road infrastructure development for logistics
- Location should be close to commercial place/hub of the country, where it is easy to connect the port by road/rail/inland water

8.) Do you have any other comments you would like to mention about port developments, or about this workshop?

DoF: More research is needed related to the environmental impacts of port and harbor operation

DMA: Well done, now we notice which area/sector is important and we can start from this phase by phase

TWA: This kind of workshop is really useful because this brings the government and private sector together and gives a chance to share their knowledge and to collaborate together for the country's development

MFSL: All organizations in Maritime Industry in Myanmar should be invited

APPENDIX J : IMPACT MATRIX & ES-TOOL MOTIVATIONS

This section provides motivations and guidance for the given scores in the impact matrix in section 6.3.2 and the ecosystem-tool in section 6.3.6. For every sub-criterion from the impact matrix, a short motivation and reference is given. The measures for these criteria are discussed in section 6.3.2.

Table 45: Motivation impact matrix criterion 'Environmental impact'

Site	Mangroves	Protected area's	Dredging impact
Pathein	Risks for mangroves along Pathein river. Proposed port site far away from mangroves.	70 km away from closest protected area	Sheltered lagoon with stable coastlines. No estuary. However dredging required from site to Pathein (PIC).
Yangon	Mangrove presence to the western side of the estuary.	60 km away from closest protected area	Large sedimentation problems near river mouth. Shallow areas. 1-2 km of land accretion last 20 years.
Mawlamyine	Small mangrove presence, reforestation possible.	150 km away from closest protected area	Stable coastline. Large shallow wetlands.
Dawei	Mangroves already removed.	10 km away from closest protected area	Unstable coastline, tidal river which changes position.
Reference:	[2] (IADS consortium, 2017)	[3] (JICA, 2017)	[1] Google Maps, [2] (Rao, Ramaswamy, & Thwin, 2005)

Table 46: Motivation impact matrix criterion 'Social & political impact'

Site	Resettlements	Labor	Accord. to policy	Tourism imp.*
Pathein	± 1.800	± 70.000	Site not mentioned in masterplans (MP). PIC is high priority.	Negative impact on beach and nature, no cruise attractive areas.
Yangon	± 2.700	± 500.000	High priority in all masterplans.	No negative impact on (tourist) beaches/nature, large cruise opportunities.
Mawlamyine	± 1.100	± 110.000	High priority in transport MP, low in logistics MP	Small negative impact on tourist beaches
Dawei	± 10.000 removed	± 225.000	Medium priority in transport MP, medium in log. MP	Negative impact on tourist beaches/nature, large cruise opportunities.
Reference:	[1] Google Maps	[1] Google Maps	[3] (JICA, 2017), [6] (JICA, 2017)	[1] Google Maps

* = no proximity to eco-tourism sites

Table 47: Motivation impact matrix criterion 'Economic impact'

Site	Attraction to investors	Fishery impact	Impact on in. (GDP)
Pathein	PIC plans. Connection to Pathein City. No SEZ plans. No human right problems.	Pathein main fish exporter, located in Rakhine marine conservation corridor.	**2012**: 5.465 **2020:** 7.772 **2030:** 12.597
Yangon	Thilawa SEZ in proximity. Near main economic centre. No human right problems.	Not located in a marine conservation corridor	**2012**: 10.294 **2020:** 21.705 **2030:** 47.162
Mawlamyine	End of GMS economic corridor. No SEZ plans. No human right problems.	Not located in a marine conservation corridor	**2012**: 2.063 **2020:** 3.560 **2030:** 7.580
Dawei	SEZ. Economic corridor. Economic centre Dawei. Human right problems.	Located in Tanintarhyi marine conservation corridor	**2012**: 1.679 **2020:** 3.260 **2030:** 7.280

Reference:	[3] (JICA, 2017), [6] (JICA, 2017)	(Pei Ya, 2016)	

Table 48: Motivation impact matrix criterion 'Adaptivity'

Site	Potential for future expanding (land, people, industry, economic plans)
Pathein	High, low, high, medium
Yangon	High, high, high, high
Mawlamyine	Medium, low, medium, high
Dawei	Medium, low, medium, high
Reference:	[1] Google Maps, [2] (IADS consortium, 2017), [3] (JICA, 2017), [6] (JICA, 2017)

Table 49: Motivation impact matrix criterion 'Logistics/construction cost'

Site	Transport modes	Shelter	Water depth	Yangon distance
Pathein	Road, rail, IWT (large network).	Natural shelter available (bay)	7 – 10 m	196 km
Yangon	Road, rail, IWT (large network), air, best connections.	Small shelter from riverbanks near river mouth	6 – 8 m	-
Mawlamyine	Road, rail, IWT, EWEC corridor	Possibilities for shelter provided by Kalegauk Island	11 – 14 m	311 km
Dawei	Road, rail, new road, corridor avail.	No natural shelter	10 – 13 m	618 km
Reference:	[3] (JICA, 2017), [6] (JICA, 2017), [7] research results	[1] Google Maps	[5] British Admiralty Charts	[1] Google Maps

Table 50: Motivation impact matrix criterion 'Feasibility/schedule'

Site	Timespan	Level of complexity
Pathein	Feasibility study phase	Bad access to site, natural bay, flat terrain.
Yangon	Feasibility study phase. Data available from Thilawa	No protected areas, large tidal flows, good connection for supply.
Mawlamyine	Feasibility study phase	Sheltered areas, good connection, offshore location is more complex.
Dawei	Construction phase (suspended)	Already under construction (financing problems)
Reference:	[3] (JICA, 2017), [6] (JICA, 2017)	

In section 6.3.6, the results of the ecosystem-tool are presented. The motivations for assigning plusses or minuses to specific interrelations is provided below. Neutral scores ('0') are not motivated because according to the author the interrelation is absent or can be neglected. The ecosystem-tool results for the sub-region 'river mouth' is presented below with the accompanying motivations.

		Horizontal: Ecosysem services (UNEP, 2011) / Vertical: Deep sea port elements		1. Seafood/fisheries	2. Fresh water storage and provision	3. Offshore energy	4. Flood protection	5. Erosion and accretion regulation	6. Wildlife habitat and biodiversity	7. Climate regulation	8. Recreation and (eco-tourism)	9. Aestethic and visual aspects
				Provisioning			Regulating & supporting				Cultural	
				2	0	2	3	3	2	3	1	1
1.	Deep sea port	Structural elements: quay walls, breakwaters, jetties	5	++	0	+	±	++	+	-	++	±
2.	Deep sea port	CAPEX dredging of approach channel & basins	5	0	0	0	+	+	-	-	0	0
3.	Deep sea port	OPEX dredging of approach channel & basins	5	-	0	0	++	++	--	--	0	0
4.	Deep sea port	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	±	0	0	0
5.	Deep sea port	Construction & maintenance	5	0	0	+	0	+	-	-	0	-
6.	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	0	--	-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8.	Operations	Marine activities: fishing, tugboats, sailing	3	-	0	0	0	0	0	0	+	+

Port element	**Interrelation between port element and ES 'Seafood/fisheries'**
1.	Port development offers opportunities for small fishery jetties and storage areas
3.	Maintenance dredging disturbs fishery activities (if present)
6.	Continuous vessel presence disturbs fish species and fishery activities
7.	Onshore activities may cause waste run-off
8.	Other marine activities may also disturb fishery activities in the proximity of the port

Port element	**Interrelation between port element and ES 'Fresh water storage and provision'**
7.	Onshore activities may cause waste run-off. However, the port sites are not located near fresh water areas.

Port element	**Interrelation between port element and ES 'Offshore energy'**
1.	Stuctural elements provide opportunities for creating wind farms and solar power areas.
5.	During construction & maintenance of the port, attention can be paid to these energy sources as well.

Port element	**Interrelation between port element and ES 'Flood protection'**
1.	Structural elements deviate flows which disturb the balanced situation. Deepening of the area allows more water to flow through the area.
2.	Deepening of the area allows more water to flow through the area.
3.	OPEX dredging maintain large depths, material can be used for flood protection.

Port element	**Interrelation between port element and ES 'Erosion and accretion regulation'**
1.	A port along the river banks helps in preventing erosion at this specific site.
2.	CAPEX dredging material can be used to nourish erosive areas.
3.	OPEX dredging will be lower in erosive areas and can be used to nourish other erosive areas.

5.	During construction & maintenance, erosion & sedimentation monitoring can be carried out to map the sedimentation problems in the area.

Port element	**Interrelation between port element and ES 'Wildlife habitat and biodiversity'**
1.	Structural elements can be home to oyster reefs, fish species and flora.
2.	Dredging activities harm wildlife habitats and biodiversity.
3.	Dredging activities harm wildlife habitats and biodiversity.
4.	Bottom structures offer habitat opportunities, but can also alter/destroy them.
5.	Construction activities harm habitats.
6.	Vessel presence and construction activities harm habitats.
7.	Waste water run-off may harm habitats.

Port element	**Interrelation between port element and ES 'Climate regulation'**
1.	Structural elements may destroy carbon sinks.
2.	Dredging activities may destroy carbon sinks and lowers air quality.
3.	Dredging activities may destroy carbon sinks and lowers air quality.
5.	Construction & maintenance of the port may destroy carbon sinks and lowers air quality.
6.	Lowers air quality.
7.	Lowers air quality.

Port element	**Interrelation between port element and ES 'Regulation and (eco)-tourism'**
1.	The port area can serve as information centre, viewpoint, tour starting point etc. The port also can provide facilities for cruise ships and ferries.
7.	Port activities can be used for port tours.
8.	Cruise and ferry ships boost the attraction to tourists.

Port element	**Interrelation between port element and ES 'Aesthetic and visual aspects'**
1.	It is doubted whether a port is attractive or not to the local people.
5.	Construction activities are often considered to be disturbing.
6.	Vessel presence causes noise nuisance and lowers air quality of the surrounding.
7.	Industry causes noise nuisance and lowers air quality of the surrounding.
8.	Recreational marine activities may increase the aesthetic value of the port.

The ecosystem-tool results for the sub-region ‘mangroves is presented below with the accompanying motivations.

		Horizontal: Ecosysem services (UNEP, 2011) / Vertical: Deep sea port elements		Provisioning: 1. Seafood/fisheries	Provisioning: 2. Fresh water storage and provision	Provisioning: 3. Offshore energy	Regulating & supporting: 4. Flood protection	Regulating & supporting: 5. Erosion and accretion regulation	Regulating & supporting: 6. Wildlife habitat and biodiversity	Regulating & supporting: 7. Climate regulation	Cultural: 8. Recreation and (eco-tourism)	Cultural: 9. Aestethic and visual aspects
				4	0	0	5	5	5	5	3	3
1.	Deep seaport	Structural elements: quay walls, breakwaters, jetties	4	++	0	+	-	-	+	-	++	±
2.	Deep seaport	CAPEX dredging of approach channel & basins	3	0	0	0	--	--	--	-	+	0
3.	Deep seaport	OPEX dredging of approach channel & basins	2	-	0	0	-	±	--	--	+	0
4.	Deep seaport	Bottom structures: jetty anchoring, navigation marks	3	0	0	0	0	0	±	0	0	0
5.	Deep seaport	Construction & maintenance	5	0	0	+	-	0	+	-	0	-
6	Operations	Vessel presence: mooring, wasters, engine nuisance	3	--	0	0	0	-	--	-	0	-
7.	Operations	Onshore activities: loading, unloading, industries	3	-	-	0	0	0	-	-	+	±
8	Operations	Marine activities: fishing, tugboats, sailing	4	-	0	0	0	0	0	-	+	+

Port element	**Interrelation between port element and ES ‘Seafood/fisheries’**
1.	Port development offers opportunities for small fishery jetties and storage areas.
3.	CAPEX dredging is only temporary disturbance.
6.	Continuous vessel presence disturbs fish species and fishery activities.
7.	Onshore activities may cause waste run-off.
8.	Other marine activities may also disturb fishery activities in the proximity of the port.

Port element	**Interrelation between port element and ES ‘Fresh water storage and provision’**
7.	Onshore activities may cause waste run-off. However, the port sites are not located near fresh water areas.

Port element	**Interrelation between port element and ES ‘Offshore energy’**
1.	Stuctural elements provide opportunities for creating wind farms and solar power areas.
5.	During construction & maintenance of the port, attention can be paid to these energy sources as well.

Port element	**Interrelation between port element and ES ‘Flood protection’**
1.	If mangroves are replaced by structural elements, the stable morphological situation will change and flood protection abilities will decrease.
2.	Dredging works affecting sediment supply and the right conditions for mangroves may result in fewer mangroves and less flood protection services obtained. Especially during CAPEX dredging this is the case because then the change in conditions is the biggest.
3.	Dredging works affecting sediment supply and the right conditions for mangroves may result in fewer mangroves and less flood protection services obtain.
5.	Construction & maintenance work may change the ideal conditions for mangroves and their flood-resisting capabilities.

Port element	**Interrelation between port element and ES 'Erosion and accretion regulation'**
1.	If mangroves are replaced by structural elements, the stable morphological situation will change and the ability to trap sediment will decrease.
2.	Dredging works affecting sediment supply and the right conditions for mangroves may result in fewer mangroves and less flood protection services obtained.
3.	Dredging works affecting sediment supply and the right conditions for mangroves may result in fewer mangroves and less flood protection services obtain. However dredged material may be used to nourish the mangrove areas.
6.	Propeller wash can cause high flow velocities and wash sediment away in mangrove areas.

Port element	**Interrelation between port element and ES 'Wildlife habitat and biodiversity'**
1.	Structural elements can be home to oyster reefs, fish species and flora.
2.	Dredging activities need to be carried out with caution in order to minimize disturbance of habitats and the living conditions of mangroves.
3.	Dredging activities need to be carried out with caution in order to minimize disturbance of habitats and the living conditions of mangroves.
4.	Bottom structures offer habitat opportunities, but can also alter/destroy them.
5.	During construction & maintenance, the mangroves could be monitored and if needed replaced so habitats can change their location.
6.	In areas with rich biodiversity, vessel presence causes large hindrance to habitats.
7.	Waste water run-off from industry may harm habitat and wildlife.

Port element	**Interrelation between port element and ES 'Climate regulation'**
1, 2, 3, 5, 6, 7, 8	Mangroves help with improving air quality and act as carbon sink. All elements of the port which cause degradation of the mangroves and additionally increase the emission of greenhouse gasses cause degradation of the ecosystem service climate regulation.

Port element	**Interrelation between port element and ES 'Recreation and (eco)-tourism'**
1.	The port area can serve as information centre, viewpoint, tour starting point etc. Besides offers jetties for cruise ships, ferries, yachts.
2.	If the sandy dredged material is suitable as beach material, beaches in the proximity can be nourished. Mangrove areas are often areas with high touristic attraction.
3.	If the sandy dredged material is suitable as beach material, beaches in the proximity can be nourished. Mangrove areas are often areas with high touristic attraction.
7.	Port activities can be used for port tours.
8.	Cruise and ferry ships boost the attraction to tourists.

Port element	**Interrelation between port element and ES 'Aesthetic and visual aspects'**
1.	It is doubted whether a port is attractive or not to the local people.
5.	Construction activities are often considered to be disturbing.
6.	Vessel presence causes noise nuisance and lowers air quality of the surrounding.
7.	Industry causes noise nuisance and lowers air quality of the surrounding.
8.	Recreational marine activities may increase the aesthetic value of the port.

APPENDIX K : HYDROGRAPHICAL CHARTS

This section provides the complete hydrographical charts used in section 7.

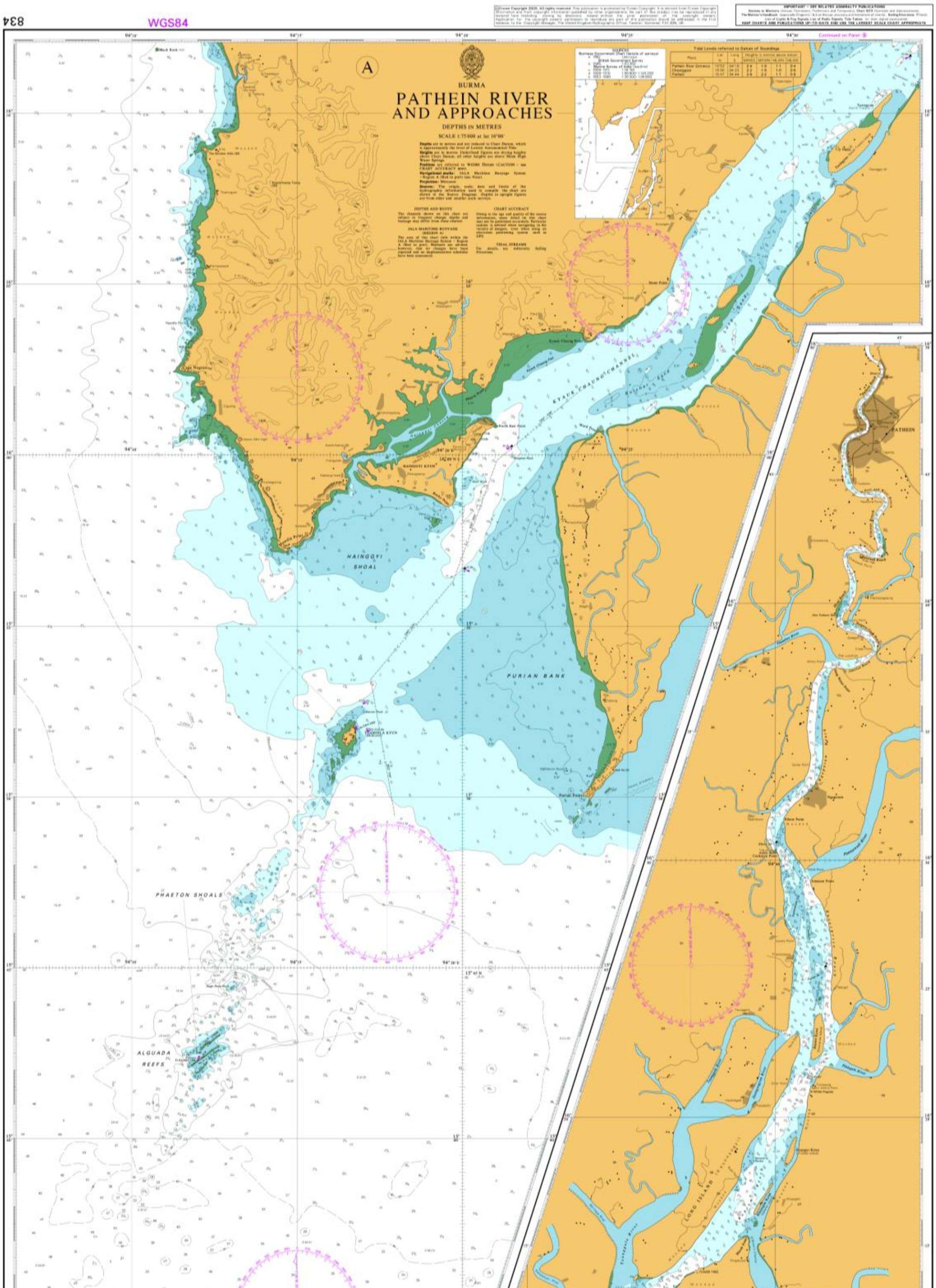


Figure 74: Hydrographical chart Pathein river and approaches

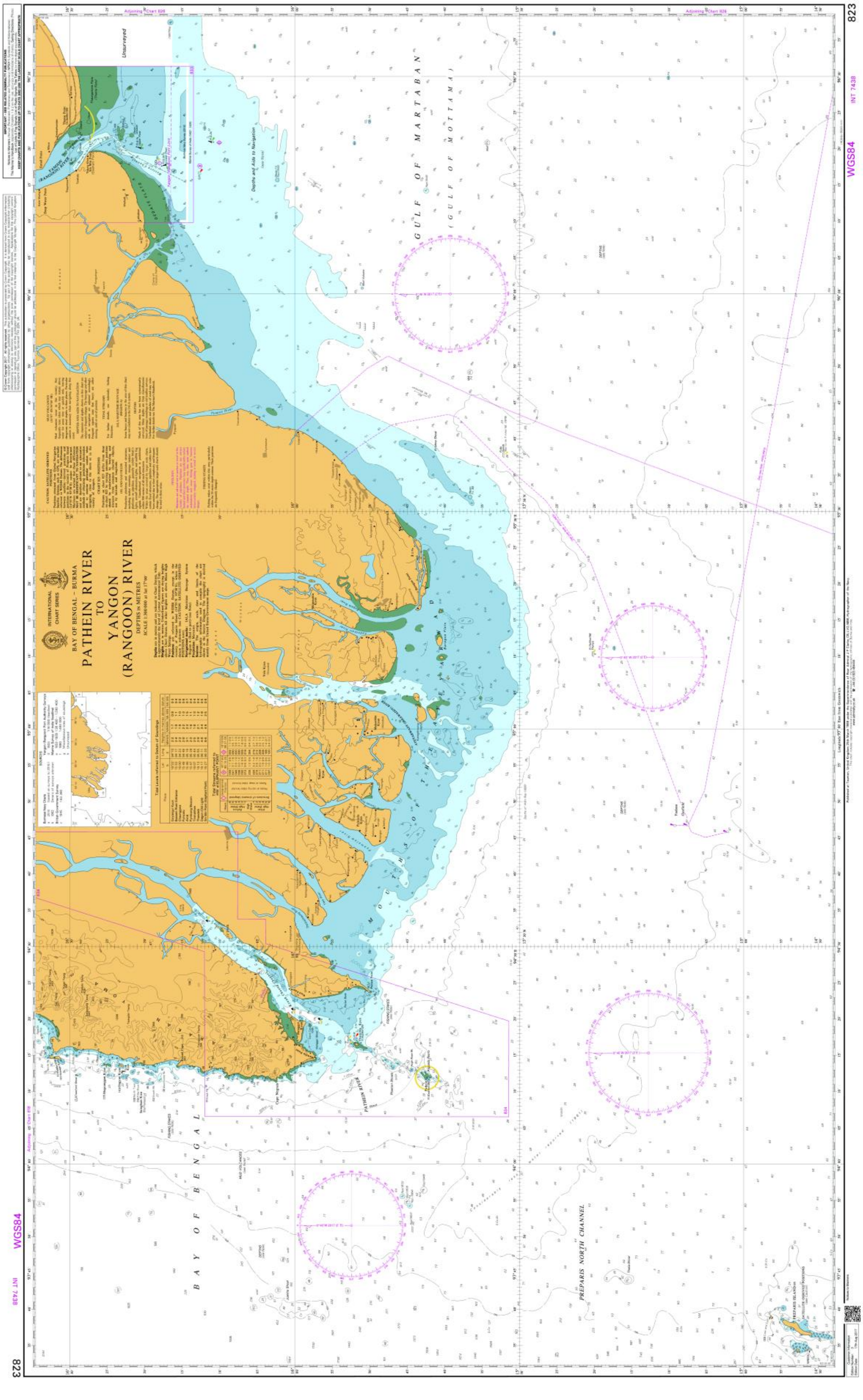


Figure 75: Hydrographical chart Pathein river to Yangon river

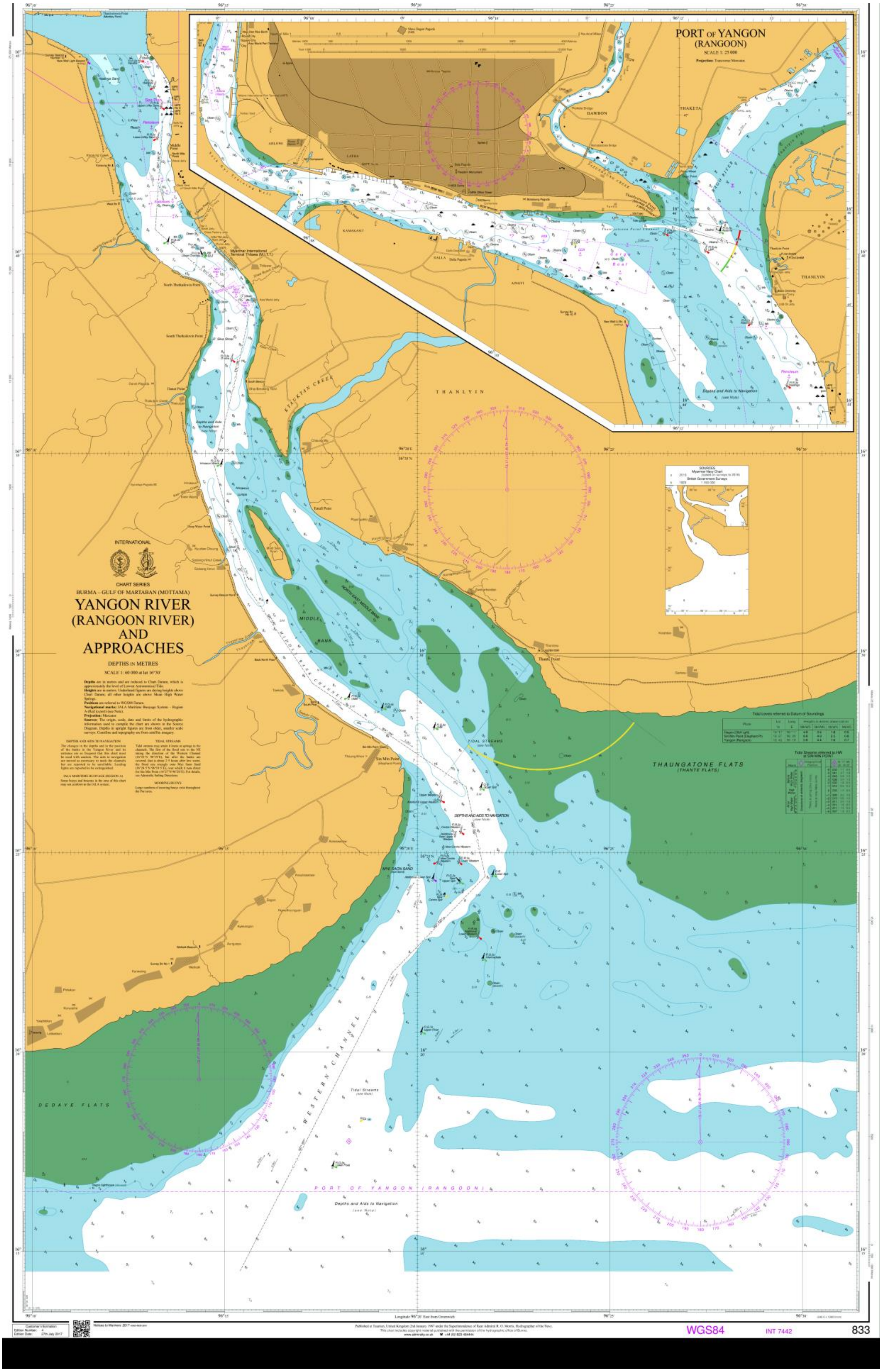


Figure 76: Hydrographical chart Yangon river and approaches

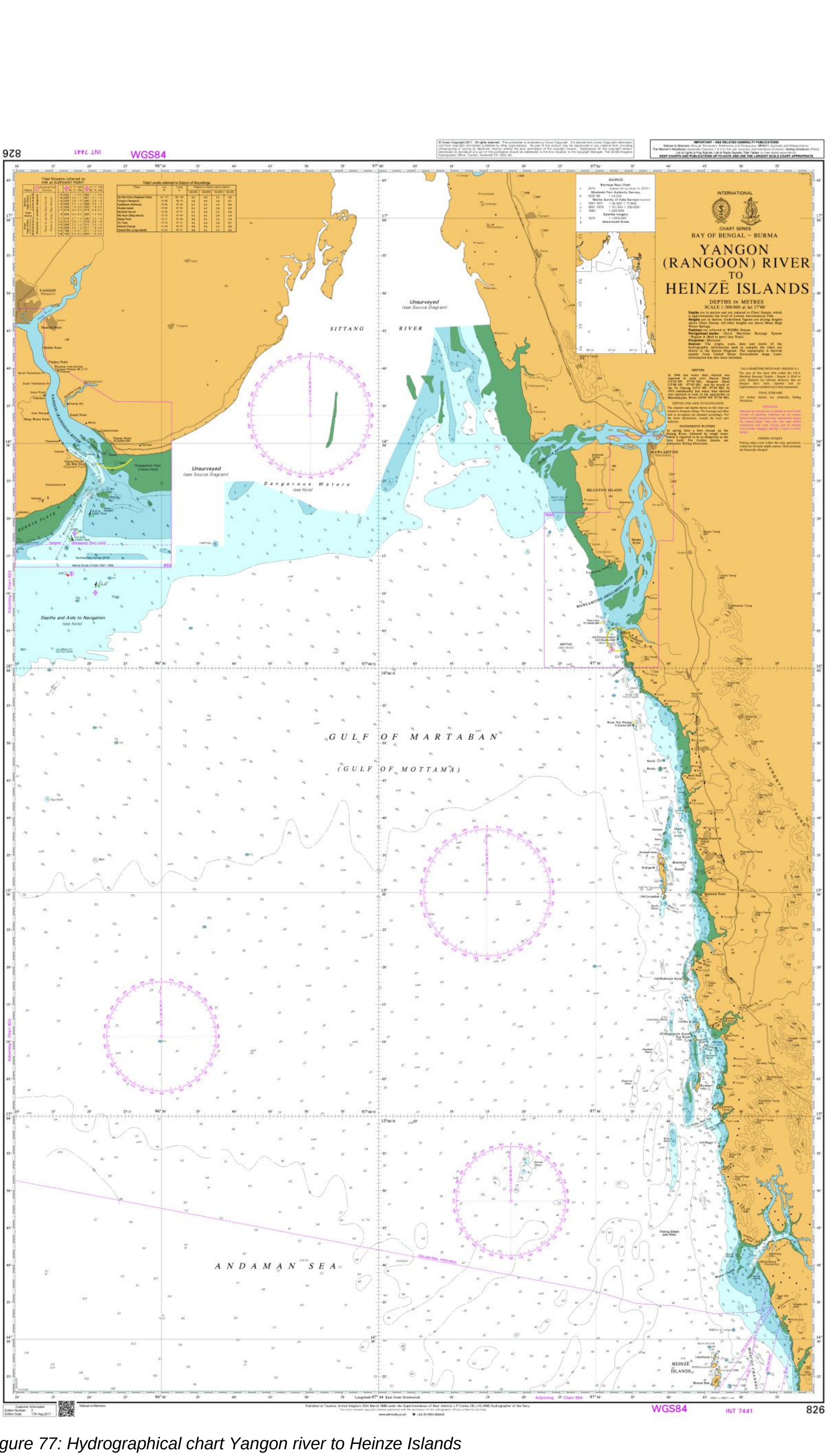
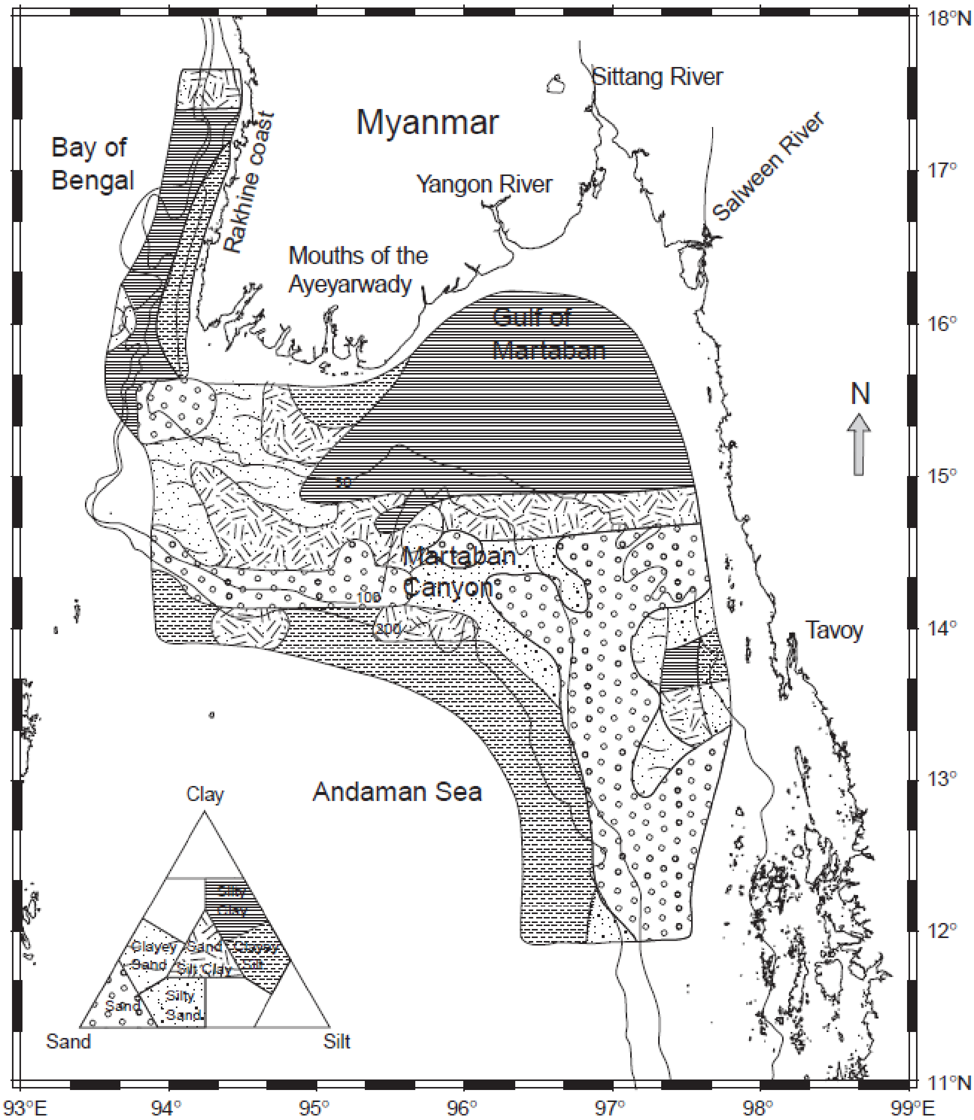


Figure 77: Hydrographical chart Yangon river to Heinze Islands



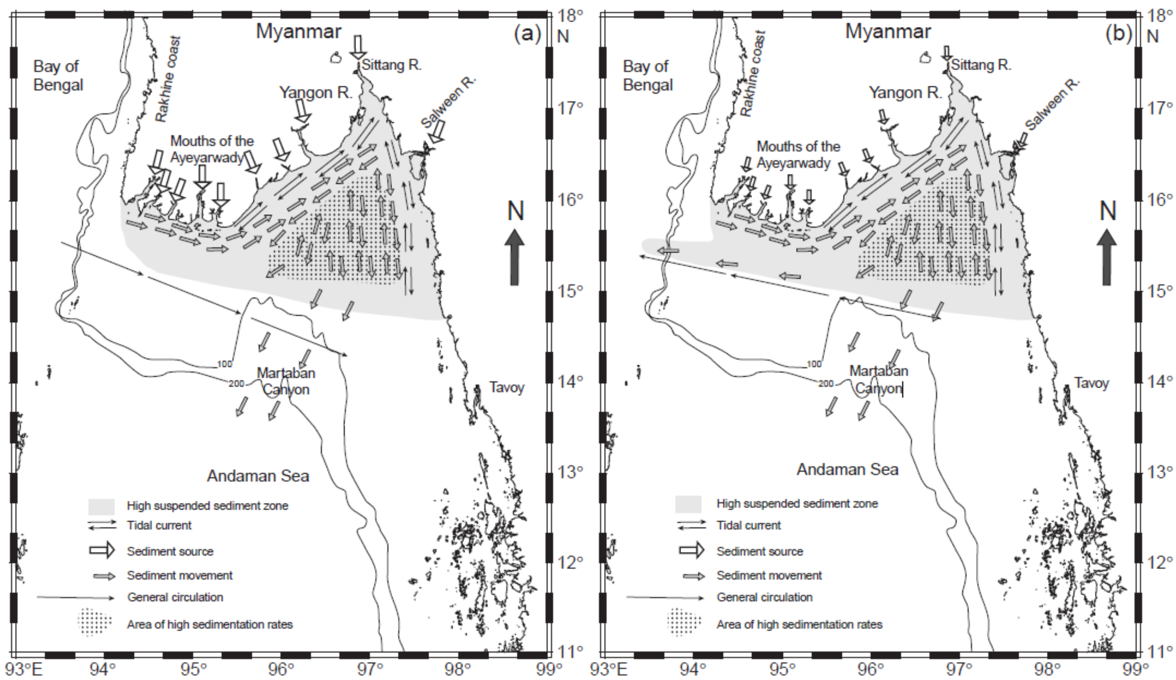


Fig. 4. Schematic diagram showing sediment sources, transport pathways and depositional areas on the Ayeyarwady shelf. (a) During the SW monsoon, sediment discharge is high and general circulation is towards east. (b) During the NE monsoon, sediment discharge is low and general circulation is towards west.

APPENDIX L : CALCULATIONS PORT AREA

Zoning of the port means dividing the total port area into different zones for specific terminals and remaining buildings and offices. Based on the requirements study in section 3.2 a container terminal, dry bulk terminal, general cargo terminal and a Ro/Ro terminal will be included in the lay-out. Arcadis (2013) advised a container terminal and a general cargo terminal, however the forecast showed that a significant part of the cargo will be bulk or agri-bulk cargo. Zoning can be seen as a partly creative process, however design principles exist. For the different commodities, estimates will be made for the required area based on Ligteringen (2017). The cargo volumes for the different commodities can be found in Table 51.

Table 51: Low case and high case cargo volumes for lay-out calculations

Commodity	Type	Low case	High case	Year
Containers	Import	2.5 mln. TEU	3.7 mln. TEU	2030
	Export	1.5 mln. TEU	2.3 mln. TEU	2030
	Total	4 mln. TEU	6 mln. TEU	2030
General Cargo	Import	2.2 mln. ton	2.7 mln. ton	2030
	Export	0.6 mln. ton	0.8 mln. ton	2030
	Total	2.8 mln. ton	3.5 mln. ton	2030
Dry Bulk	Import	1.2 mln ton	1.6 mln. ton	2030
	Export	0.8 mln ton	1.0 mln. ton	2030
	Total	2.0 mln. ton	2.6 mln. ton	2030
Ro/Ro	Import	270.000 cars	430.000 cars	2030
	Export	0	0	2030
	Total	270.000 cars	430.000 cars	2030

The numbers in the above table are only used to provide an indication of the required areas and in reality, the numbers may be significantly higher or lower (or show a large difference between the high case and the low case)

Containers

At the time of master planning the future terminal operator is often unknown. In this case, the port planner will apply general principles and sufficient flexibility should be created in the lay-out to be able to accommodate future users. The terminal lay-out depends to a certain extent on the chosen handling systems. For the container terminal, the following elements have to be determined and quantified: quay length and number of cranes, apron area, storage area, container transfer area, buildings. The dimensions of these elements are a function of the yearly averaged flows of containers presented below.

Commodity	Type	Low case	High case	Year
Containers	Import	2.5 mln. TEU	3.7 mln. TEU	2030
	Export	1.5 mln. TEU	2.3 mln. TEU	2030
	Total	4 mln. TEU	6 mln. TEU	2030

At first, the average berth productivity should be calculated:

$c_b = P * f_{TEU} * N_{cb} * n_{hy} * m_b$, in which:

c_b = average annual productivity per berth [TEU/yr]

P = net production per crane [moves/hr]

f_{TEU} = TEU factor (ratio 20 ft TEU and 40 ft. TEU) [-]

N_{cb} = number of cranes per berth [-]

n_{hy} = number of operational hours per year [-]

m_b = berth occupancy factor [-]

$\boldsymbol{P}$	$\boldsymbol{f_{TEU}}$	$\boldsymbol{N_{cb}}$	$\boldsymbol{n_{hy}}$	$\boldsymbol{m_b}$	$\boldsymbol{c_b}$
25	1.5	3	8640	0.4	388.880

The number of berths 'n' is calculated as follows:

$$n = \frac{c}{c_b}$$

Containers c (TEU)	1 mln.	2 mln.	3 mln.	**4 mln.**	5 mln.	**6 mln.**	7 mln.
Berths n (-)	3	5	8	**10**	13	**16**	18

In which 'c' is the total number of TEU entering and leaving the terminal by seagoing vessels. The bold columns denote total number of containers in the low and high case. This number of berths is rather high to start with in Myanmar, and therefore it is recommended to start with 1-3 berths and expand towards 10 berths after several years and based on the cargo growth. Finally the length of the quay can be calculated:

$$L_q = \begin{cases} L_{s,max} + 2 * 15 & n = 1 \\ 1.1 * n * (L_{s,avg} + 15) + 15 & n > 1 \end{cases}$$

$L_{s,avg}$ = 300 m

Containers (TEU)	1 mln.	2 mln.	3 mln.	**4 mln.**	5 mln.	**6 mln.**	7 mln.
Berths (-)	3	5	8	**10**	13	**16**	18
Quay length (km)	0.9	1.8	2.7	**3.6**	4.5	**5.4**	6.3

The next step is calculating the storage yard of the container terminal. This storage yard is divided into stacks for export, import, reefers, hazardous cargo and empties. The surface area requirements for the separate stacks can be calculated as follows:

$$A = \frac{N_c * t_d * A_{TEU}}{r_{st} * 365 * m_c}$$

A = area required (m²) N_c = number of container movements per year per type of stack in TEU's

t_d = average dwell time (days) A_{TEU} = required area per TEU inclusive equipment travelling lanes (m²)

h_s = average stacking height m_c = acceptable average occupancy rate

Type	N_c	t_d	A_{TEU}	h_s	m_c
Import	2.5–3.7 mln.	10	10	0.6	0.7
Export	1.5-2.3 mln.	8	10	0.8	0.7
Empties	0.5-0.8 mln.	12	10	0.9	0.8

The calculation for the Container Freight Station (CFS) area does not follow the formula for calculating the areas for import and export. A CFS is used for cargo which is imported in one container, but has different destinations (stripping), or which comes from different origins and is loaded into one container for export (stuffing):

$$A_{cfs} = \frac{N_c * V * t_d * f_{area} * f_{bulk}}{h_s * m_c * 365}$$

N_c = number of TEU moved through CFS (TEU/yr) f_{bulk} = bulking factor

V = contents of 1 TEU container (1 container = 29 m³) h_s= average stacking height of cargo (m)

f_{area} = ratio gross area over net area m_c = acceptable occupancy rate

Type	N_c	t_d	V	f_{area}	f_{bulk}	h_s	m_c
CFS	0.5-1 mln.	5	29	1.4	1.2	0.75	0.65

The different required areas are displayed in below table.

	Import (ha)	**Export (ha)**	**Empties (ha)**	**CFS (ha)**	**Total (ha)**
Low case	163	59	23	68	313
High case	241	90	37	136	504

General cargo

Although containerized cargo has surpassed general cargo volumes in terms of tonnes cargo and will grow even further, General Cargo (GC) terminals will maintain its function for specific commodities, such as neo-bulk (steel products, non-ferro products, forest products). The calculations for the general cargo terminal are similar to the calculations for the container terminal. The yearly averaged general cargo flows are presented below.

Commodity	Type	Low case	High case	Year
General Cargo	Import	2.2 mln. ton	2.7 mln. ton	2030
	Export	0.6 mln. ton	0.8 mln. ton	2030
	Total	2.8 mln. ton	3.5 mln. ton	2030

The throughput of a GC berth is calculated as follows:

$c_b = P * N_{gs} * n_{hy} * m_b$, in which:

c_b = throughput per berth [t/yr]

P = average gang productivity [t/hr]

N_{gs} = number of gangs per ship [-]

n_{hy} = number of operational hours per year [-]

m_b = berth occupancy rate r [-]

$\boldsymbol{P}$	$\boldsymbol{N_{gs}}$	$\boldsymbol{n_{hy}}$	$\boldsymbol{m_b}$	$\boldsymbol{c_b}$
25	3	8640	0.7	453.600

Subsequently the number of required berths is determined:

$$n = \frac{C}{c_b}$$

in which C is the required throughput across the terminal in t/yr.

Cargo (ton/yr)	1.5 mln.	1.9 mln.	2.3 mln.	**2.7 mln.**	3.1 mln.	**3.5 mln.**	3.9 mln.
Berths n (-)	4	5	5	**6**	7	**8**	9

The quay length is calculated in the same way as for the container terminal:

$$L_q = \begin{cases} L_{s,max} + 2 * 15 & n = 1 \\ 1.1 * n * \left(L_{s,avg} + 15\right) + 15 & n > 1 \end{cases}$$

$L_{s,avg}$ = 250 m

Cargo (ton/yr)	1.5 mln.	1.9 mln.	2.3 mln.	**2.7 mln.**	3.1 mln.	**3.5 mln.**	3.9 mln.
Berths n (-)	4	5	5	**6**	7	**8**	9
Quay length (km)	0.98	1.24	1.49	**1.75**	2.0	**2.26**	2.52

The required storage area for the general cargo terminal is calculated with:

$$A_{gr} = \frac{f_{area} * f_{bulk} * N_c * t_d}{m_c * h_s * \rho_{cargo} * 365}$$

N_c = total annual throughput which passes transit

ρ_{cargo} = average relative density as stowed in ship

f_{bulk} = bulking factor

t_d = average dwell time of cargo in days

f_{area} = ratio gross over net surface

m_c = average rate of occupancy

Type	$\boldsymbol{f_{area}}$	$\boldsymbol{f_{bulk}}$	$\boldsymbol{N_c}$	$\boldsymbol{t_d}$	$\boldsymbol{m_c}$	$\boldsymbol{h_s}$	$\boldsymbol{\rho_{cargo}}$
Transit	1.5	1.2	2.7-3.5 mln.	10	0.7	2	0.6

The required areas for general cargo are as follows:

	Transit shed (ha)
Low case	16
High case	21

The required areas for containerized cargo are as follows:

	Import (ha)	Export (ha)	Empties (ha)	CFS (ha)	Total (ha)
Low case	163	59	23	68	313
High case	241	90	37	136	504

Dry bulk

Contrary to virtually all other terminals, dry bulk terminals are often designed for one-way traffic which causes the loading and unloading terminals to be different in character. The best location of a dry bulk terminal for export is in the vicinity of the origin of the commodity (e.g. iron core, coal, grain, rice, gypsum, fish). Due to the large quantities often handled in these ports, extensive storage facilities are required and the necessary land has to be available. Unloading or import terminals are much more diverse, both in location, size and cargo handling system (Ligteringen & Velsink, 2017). The yearly averaged dry bulk flows used are:

Commodity	Type	Low case	High case	Year
Dry Bulk	Import	1.2 mln ton	1.6 mln. ton	2030
	Export	0.8 mln ton	1.0 mln. ton	2030
	Total	2.0 mln. ton	2.6 mln. ton	2030

A first order estimate of the total length and width required for the stockpiles can be made with the equation:

$$V = b * \frac{1}{2} * h * l * m_b = \frac{1}{2} * h * x * m_b$$

V = maximum volume of cargo in storage

l = total length of the stockpile

b = width of the stockpile

m_b = utilization rate

h = height of the stockpile

x = required area

In order to determine the volume of the stockpile, the tonnes of cargo in the above table should be converted to metric volumes. The average density of dry bulk in the category grains, pulses and beans is approximately 650 kg/m^3 (De Binnenvaart, 2018), similar to the average weight density of coal (Ligteringen & Velsink, 2017). The angle of repose of the stockpile is assumed to be 45^o, the utilization rate is set at 0.7, and a maximum height of the stockpiles is maintained at 10 m. The required areas for dry bulk cargo are:

	Tonnage	Volume (m^3)	Height (m)	Area (m^2)	Area (ha)
Low case	2.0 mln	3.000.000	10	880.000	88
High case	2.6 mln	4.000.000	10	1.143.000	114

Ro/Ro terminal

Roll-on/Roll-off cargo in Myanmar mainly consists of cars, shipped from Japan. A roll-on/roll-off terminal is already present at Thilawa Port to the south of Yangon, and the volume of shipped cars is not sufficiently large to create a new Ro/Ro terminal. Shipped volumes can be found in the below table.

Commodity	Type	Low case	High case	Year
Ro/Ro	Import	270.000 cars	430.000 cars	2030
	Export	0	0	2030
	Total	270.000 cars	430.000 cars	2030

Required port area

The required areas for containerized cargo are as follows:

	Import (ha)	Export (ha)	Empties (ha)	CFS (ha)	Total (ha)
Low case	163	59	23	68	313
High case	241	90	37	136	504

The required areas for general cargo and dry bulk are as follows:

	Transit shed (ha)		Stockpile (ha)
Low case	16		88
High case	21		114

This means that the total required area is 313 + 16 + 88 = 417 ha in a low case scenario, and 504 + 21 + 114 = 639 ha in a high case scenario.

Besides these dedicated areas for container cargo, general cargo, dry bulk cargo and ro/ro cargo, space is required for road and rail connection, office buildings, customs, additional industry etc. For this required space, it is assumed that this asks for approximately the same area as the calculated cargo area. A total of 800 ha is therefore recommended in the low case scenario, and 1200 ha in the high case scenario. This is the eventual required area. The port will start small and phased development will lead to a larger port.

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