Towards Sustainable Port Development in the Western Indian Ocean

Situation Assessment

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Nairobi Convention Secretariat
United Nations Environment Programme,
United Nations Avenue, Gigiri,
P.O Box 47074, Nairobi, Kenya
Tel: +254 (0)20 7621250/2025/1270 Fax: +254 (0)20 7623203
Email: nairobi.convention@unep.org

Prepared by the Council for Scientific and Industrial Research (CSIR)

Dr Susan Taljaard
Steven Weerts
Dr Heidi van Deventer

With contributions from:

Lydia Ngugi - Maritime Technologies Cooperation Centre (MTCC), Africa
Musa Alfan – MTCC, Africa
Jane Ndungu - Nairobi Convention Secretariat, Kenya
Dr Joseph Maina Mbui – Macquarie University, Australia

Council for Scientific and Industrial Research (CSIR)
Smart Places - Sustainable Ecosystems
Coastal Systems Research Group
Durban/Stellenbosch
South Africa

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EXECUTIVE SUMMARY

The port industry faces a growing challenge to address societal and environmental considerations while at the same time having to provide adequate capacity and cost-effective services to traders. With increasing societal and regulatory pressures port authorities around the world are compelled to pursue greater sustainability to safeguard their 'license to operate'. In response to these global challenges the concept of 'Green Ports' has emerged, focusing on balancing environmental challenges and economic demand and striving for sustainability through increasing both economic and environmental competitiveness. The concept of 'Sustainable Port Development' builds on that of 'Green Ports' by also considering social sustainability, in essence advocating the need for a port development to create a balance between economic growth, environmental protection, and social progress to secure its long-term future.

According to the World Bank, sustainable Blue Economy is the '*sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem'.* It strives *"to promote economic growth, social inclusion, and the preservation or improvement of livelihoods while at the same time ensuring environmental sustainability of the oceans and coastal areas"*. Aligned with this, the *Africa Blue Economy Strategy* views the Blue Economy as '*an inclusive and sustainable economy that becomes a significant contributor to continental transformation and growth, through advancing knowledge on marine and aquatic biotechnology, environmental sustainability, the growth of an Africa-wide shipping industry, the development of sea, river and lake transport, the management of fishing activities in these aquatic spaces, and the exploitation and beneficiation of deep sea mineral and other resources'*.

The Western Indian Ocean (WIO) region is currently experiencing an unprecedented growth in large-scale development which includes ports, mining, roads and railways, agriculture, and oil and gas, all principally driven by large infrastructure demands and financial inflows from different funding streams. Economic growth and development are inevitable if countries of the WIO region want to address social challenges such as poverty and inequality. Most of these developments are concentrated in coastal areas which support rich natural resources. The region has an opportunity to define sustainable trajectories for these investments, but development also has the potential to significantly impact the integrity of critical habitats and the natural resource base that future growth and societal well-being depends on. In the WIO Region coastal communities are especially reliant on coastal resources for their lives and livelihoods. Considering the rich diversity of coastal and marine ecosystems in the WIO region, and its potential to contribute to socio-economic benefits, Blue Economy growth holds great promise for the area.

Within this context, and complimentary to the *Strategic Framework for Coastal and Marine Water Quality Management in the Western Indian Ocean Region*, this Nairobi Convention project, being undertaken on request of the Conference of Parties (CoP), seeks to facilitate sustainable port development in the WIO on request of the Conference of Parties (CoP). It is part of, and supports the *Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP)* Project, informed by the appreciation that ports intersect with critical coastal and marine resources, and aligned with the WIO region's vision to grow a sustainable Blue Economy. The scientific outputs generated from this project will be shared with national governments to support and guide development of national policy options on sustainable port development through the Science to Policy Platform supported by the Nairobi Convention.

The science-based outputs generated from this project will be shared with national governments to support and guide them in the development of national policies for sustainable port development. Further, the outputs will be shared with port developers and operators in the region to support and guide them in the implementation of sustainable port development options. This will be achieved through the Science-to-Policy Platform supported by the Nairobi Convention.

To this end, a series of science-based outputs were prepared as part of this project, including:

- A Situation Assessment providing the context and backdrop for sustainable port operations and development in the WIO region
- A Scenario Analysis evaluating generic development pathways which range from 'doing-nothing' to options incorporating 'sustainable port' considerations, drawing on information in the Situation Assessment providing context and backdrop for more sustainable port development in the WIO region
- A Toolkit for Sustainable Port Development in a Blue Economy comprising practical management and operational tools aimed at port operators and managers in the WIO region towards advancing sustainable port planning and operations aligned with international best practice.
- A Policy Brief capturing proposed recommendations for future sustainable port development in a blue economy in the WIO region.

This document presents the Situation Assessment giving an overview of the status of port development in the WIO region, as well as global environmentally related advances in sustainable port development, as motivation for the promotion of sustainable port development in the WIO region.

The WIO region supports a wide array of port and harbour types, ranging from large commercial ports to small fishing jetties. These infrastructure developments fulfil important socio-economic services, but they are invariably located in sensitive coastal areas which support rich natural resources that provide other valuable nature-based goods and services to local communities. Ports inherently benefit from ecosystem services provided by sheltered coastal environments, but numerous activities undertaken in ports contribute to problems that potentially cause negative impacts on coastal ecosystems and other ecosystem services. There is a wealth of international literature which documents the potential environmental problems associated with port development and operations, including climate impacts, air pollution, water, sediment and soil pollution, physical problems including destruction of habitat or biota, harmful or invasive marine organisms and pathogens, underwater noise, and artificial light. Numerous activities undertaken in ports contribute to these problems potentially causing negative impact on the environment and associated socio-economic benefits. To achieve sustainable port development such problems need to be identified and linked to the contributing activities, to inform timeous intervention or mitigating actions by port authorities.

While environmental impacts of ports in the WIO region are apparent, environmental data to quantify such impacts are very limited, or not readily available (e.g., published in public domains). An assessment of global and regional geospatial databases on coastal habitats (e.g., mangroves, coral reefs, and seagrasses) in and around selected ports of the region revealed that most of these databases are not at suitably fine resolution to be used for quantifying impacts of port development at the scale of local port. While preliminary studies showed that remote sensing technologies such as Google Earth Engine (GEE) can provide suitable geospatial information for above ground habitats (e.g., mangroves), more sophisticated technologies should be investigated to provide geospatial data on other important coastal habitats such as coral reefs, seagrasses, and different substrate habitats (e.g., sand banks). At application at the local port scale resolution of spatial data should at least be 5 x 5 m (for strategic planning) and ideally at sub-meter resolution for detailed design and monitoring purposes.

It is strongly recommended that future development in the generation of high resolution ecological geospatial data be coordinated across countries in the region. Ideally, standard methods for the generation of such data should be developed and agreed upon. Doing so will enable the region to conduct comparative studies both spatially (across countries) and temporally (over time in specific ports). This could be achieved through the establishment of a formal Regional Network or a Community of Practice comprising data scientists and ecologists, the latter being key to assisting with ground truthing and interpretation of geospatial data. An underpinning requirement to successful implement such data technologies is commitment from port authorities, in collaboration with other regional and national networks with interests in collating and applying high resolution ecological data, to invest in such endeavours. Investment should be pre-emptive, early enough in the port development cycle to ensure that negotiations pertaining to coastal habitat protection and/or trade-offs are incorporated in port (spatial) planning from the site selection stage. These data will also be valuable later, in the operational stages, to inform port environmental monitoring programmes. Even though geospatial data for port development will be focused on the spatial demarcation of the port space, it will be important to extend geographical boundaries of geospatial data layers to adjacent near-shore systems which influence, and are influenced by, ports and port activities. Examples are anchorage areas and adjacent shorelines that may be influenced by pollution or changes in sediment dynamics because of port structure and operations. Numerical modelling techniques to simulate oceanographic circulation and pollutant transport processes are useful tools that can be used to determine such geographical boundaries.

Ports worldwide are increasingly under pressure to focus on more than just economic objectives. They are required to develop and implement resilient and sustainable strategies to include the environment and society. Whilst good progress has been made in some countries of the WIO region towards sustainable port development, it is critically important that the WIO region continuously draw and build on international advances to ensure sustainability of its ports, both existing and new. In the WIO region port developers and operators have the opportunity to define sustainable trajectories for new ports, or expansion in existing ports. Failing to do so will result in potentially detrimental impacts on critical coastal habitats and the resource base that future coastal livelihoods depend on. Output from this assessment has been used to provide context to the other science-based outputs produced as part of this this project, namely the Scenario Analysis, a Toolkit for Sustainable Port Development in a Blue Economy and a Policy Brief.

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ACRONYMS

ACP	African, Caribbean, and Pacific
ANAM	National Agency for Maritime Affairs
APC	Port Authority of the Comoros
APMF	Agence Portuaire Maritime et Fluviale (Maritime and River Port Agency)
BMPs	Best management practices
CdM	Cornelder de Moçambique
CFM	Mozambique Ports and Railways
CMTP	Comprehensive Maritime Transport Policy
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environment and Tourism
DFFE	Department of Forestry, Fisheries, and the Environment
DP World	Dubai Ports World
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EMS	Environmental Management Systems
EMAS	Eco-Management and Audit Scheme
ESIA	Environment and social impact assessment
ESPO	European Sea Ports Organisation
EVI	Enhanced vegetation index
GEE	Google Earth Engine
GEF	Global Environmental Facility
GIAMA	Government Immovable Asset Management Act (No. 19 of 2007)
GPA/LBA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
GPP	Green Port Policy
IAPH	Association of Ports and Harbours
ICDs	Internal Container Deports
IPM	Integrated Port Management
ISO	Organisation for Standardisation
KMFRI	Kenya Marine Fisheries Research Institute
KPA	Kenya Ports Authority
KPI	Key performance indicator
LBSA Protocol	Protocol for the Protection of the Marine and Coastal Environment of the Western Indian Ocean from Land-Based Sources and Activities
MARPOL	The International Convention for the Prevention of Pollution from Ships
MEAS	Multilateral Environmental Agreements project
MPA	Mauritius Ports Authority
MPDC	Maputo Port Development Company
MPMT	Ministry of Ports and Marine Transport
MoT	Ministry for Transport
MTCC	Maritime Technologies Cooperation Centre
MSAVI	Modified Soil Adjusted Vegetation Index
NDWI	Normalized Difference Water Index,
NDWBI	Normalized Difference Water Body Index
NDVI	Normalized Difference Vegetation Index
PCG	'Ports à Concession Globale'
PGA	'Autonomous Management Ports'

PIANC	World Association for Waterborne Transport Infrastructure
PIN	Ports of National Interest
PIR	Ports of Regional Interest
PPP	"People", "Planet", and "Prosperity"
PVREP	Port Victoria Extension and Rehabilitation Project
RSA	Republic of South Africa
SAPPHIRE	Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms
SAVI	Soil Adjusted Vegetation Index
SCP	Société Comorienne des Ports
SDG	Sustainable Development Goals
SEA	Strategic environmental assessment
Simple ratio RN	Red and NIR bands
Simple ratio SN	SWIR and NIR bands
SLR	Sea level rise
SRTM	Shuttle Radar Topography Mission
SPA	Seychelles Port Authority
SFA	Seychelles Fishing Authority
SBM	Single buoy mooring
TEU	Twenty-foot equivalent unit
TNPA	Transnet National Ports Authority
TPA	Tanzania Ports Authority
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
WIO	West Indian Ocean
WIO-Lab	Addressing Land-based Activities in the West Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIOSAP	Western Indian Ocean Strategic Action Programme
WPSP	World Ports Sustainability Program
UN	United Nations
US-EPA	United State Environmental Protection Agency
UNEP FI	United Nations Environment Programme Finance Initiative
UNDG	United Nations Development Group
ZPC	Zanzibar Ports Corporation
ZMA	Zanzibar Maritime Authority

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The following collaborators are thanked for their contribution:

- Dr Jared Bosire - Nairobi Convention Secretariat, Kenya
- Dr Joseph Maina Mbui – Macquarie University, Australia
- Lydia Ngugi - Maritime Technologies Cooperation Centre (MTCC), Africa
- Dr Arthur Tuda - Western Indian Ocean Marine Science Association
- Jane Ndungu - Nairobi Convention Secretariat, Kenya
- Nathan Majwa - Nairobi Convention Secretariat, Kenya

The following representatives from the contracting parties are thanked for their contribution:

COUNTRY	STAKEHOLDER	AFFILIATION
Australia	Joseph Maina Mbui	Senior Lecturer, Macquarie University
Comoros	Abdillah Soifoine	Head of marine pollution department, National Agency of Maritimes Affaires (ANAM)
	Abdoulkarim Youssouf	Chef des operations Pilote, Port Moroni
	Hadidja Bacar	Blue Economy, Direction of Environment
	Issouf Ambadi	Directorate General of Environment
Ethiopia	Linda Amornghor-Oje Etta	Blue Economy Coordinator, African Union (AU), Addis Ababa
Kenya	Daniel Njuguna Mwaura	Director of Planning, State Department for Shipping and Maritime
	Jared Bosire	Nairobi Convention Secretariat, Ecosystems Division United Nations Environment Programme (UNEP)
	Nathan Majwa	Nairobi Convention Secretariat, Ecosystems Division UNEP
	Jane Ndungu	Nairobi Convention Secretariat, Ecosystems Division UNEP
	Caroline Bii	Nairobi Convention Secretariat, Ecosystems Division UNEP
	Hiram Ndir	Project director, JKUAT/MTCC-Africa
	Omary Mzuzuri	Mombasa
	Agnes Wangui Muthumbi	University of Nairobi
	Mohamed Hassan	Kenya Ports Authority, Mombasa
	Lydia Muthoni Ngugi	Head, Maritime Technology Cooperation Centre Africa
	Musa Jeffer	ICT, Maritime Technology Cooperation Centre Africa
	Jennifer O'lear	Wildlife Conservation Society
	Dan Ashitiva	National Environment Management Authority (NEMA)
	Joan Mutua	Jomo Kenyatta University of Agriculture and Technology (JKUAT)
	Florence Bet	Kenya Ports Authority
	Stellamaris Muthike	Environmental Officer, Kenya Maritime Authority (KMA)
	Zacharia Kingori	Intergovernmental Authority on Development (IGAD)
	Maxwell Azali	Wildlife Conservation Society
	Mamo B. Mamo	Director General, National Environment Management Authority (NEMA)
	Ruth Mungai	Economist (Projects), Port Management Association of Eastern and Southern Africa (PMAESA) Secretariat
	Col. Andre Didace Ciseau	Secretary General, Port Management Association of Eastern and Southern Africa (PMAESA)
	Mubarak Sodha	Projects Development and ICT Officer, PMAESA
	Tuqa Jirmo	Project Manager, Blue Economy WIO - The Nature Conservancy, Nairobi
	John Gerald Odhiambo	Jomo Kenyatta University of Agriculture & Technology
	James Kairo	Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa
Madagascar	Hary Lys Jean Louis	Administrator of Port Affairs, Port, Maritime and Waterways Agency (APMF:
	Johanne Francia Anja Harivelo	Administrator of Port Affairs, Head of International Affairs Section, Port, Maritime and Waterways Agency (APMF) General of International and Environmental Affairs
	Yves Mong	Directorate General of Environment Centre National de Recherches sur l'Environnement
	Soloniainanirinanandrianina Hary Lys Jean Louis	Port, Maritime and Waterways Agency (APMF)
	Jacquis Rasoanaina	Ministère de l'Environnment, de l'Ecologie, de la Mer et des Forêts

COUNTRY	STAKEHOLDER	AFFILIATION
Mauritius	Ibne Al Shanawaz Purdhun	Environment Officer, Ministry of Environment, Solid Waste Management and Climate Change
	Sohatee-Tuloo Parvatee	Acting senior maritime officer, Ministry of Blue Economy, Marine Resources, Fisheries & Shipping (Shipping Division)
	Rughooputh, Bussunth Kumar	Mauritius Ports Authority
Mozambique	Maria Florinda Cambula	Ministry of Land, Environment and Rural Development
	Abudo De Klerk Kristina Jaime	Port Authority Director, Maputo Port Development Company (MPDC)
	Sidonia Muhorro	Ministry of Land, Environment and Rural Development
	Alexandre Bartolomeu	Ministry of Land, Environment and Rural Development
	Jeronimo Tamele	HSE Manager, Maputo Port Development Company (MPDC)
	Salomão Bandeira	Universidade Eduardo Mondlane, Maputo
Seychelles	Laporte Patrick Goldbe Franky	Director of Project and Infrastructure, Seychelles Ports Authority
	Joachim Valmont	CEO, Seychelles Maritime Safety Authority Victoria, Mahe
	Gabriel Michael Randy	Flag State Surveyor, Seychelles Maritime Safety Authority
	Myron Meme	Director, Environment Assessment & Permit Section Mahé
South Africa	Obakeng Molelu	Bandari Bora Project
	Yamkela Mngxe	Chief Directorate: Specialist monitoring services, Department of Environmental Affairs — Ocean and Coasts Branch
	Susan Taljaard	Council for Scientific and Industrial Research (CSIR)
	Mojafi Tebogo Abia	South African Maritime Safety Authority (SAMSA)
	Steven Weerts	Council for Scientific and Industrial Research (CSIR)
	Cebile Nzuza	Senior Manager, Environment & Sustainability, Transnet National Ports Authority (TNPA)
Tanzania	Blandina Lugendo	University of Dar es Salaam
	Eng. Selestine Mkenda	Manager Navigation, Security and Marine environmental Tanzania Shipping Agencies Corporation (TASAC)
	Dismas Mwikila	East African Community (EAC)
	Capt. Emmanuel Marijani	Principal Flag & Port state control officer, TASAC
	Rashid Mansour Ameir	Operation manager, Zanzibar Ports Corporation
	Japhet J. Kashaigili,	Sokoine University of Agriculture (SUA)
	Joseph M Mkumbo	Flag & Port state control Officer, TASAC
	Simon Lugandu	Director, Wildlife Conservation Society
	Clement W. Kamendu	Chairman, Dar Port Capacity Optimization Steering Committee (DPCO-SC)
	Rajab Ali Rajab	Director Port and Shipping, Zanzibar Maritime Authority:
	Arthur Tuda	Executive Secretary, Western Indian Ocean Marine Science Association (WIOMSA)
	Kaimu Abdi Mkeyenge	Director General, TASAC
	Julius Francis	University of Dar es Salaam
	Asma Mohamed	Senior Legal Officer, TASAC
	Magdalena Gerald Ngotolainyo	Vice President's Office, Department of Environment Dodoma
	Margareth Kyewalyanga	University of Dar es Salaam
	Bakari Mhando	Public Relations Officer, TASAC
	Nicholous Kinyariri	Public Relations Officer, TASAC
	Capt. Abdullah Mwingamno	Director of Marine & Ports Operations (Harbour Master), Tanzania Ports Authority
	Jesca Oscar Kamyongo	Tanzania Shipping Agencies Corporation (TASAC)
	Claudianus Kunze	Tanzania Ports Authority
	George S. Fasha	Tanzania Ports Authority
	Fahd Al-Guthmy	WCS Maimba Yetu Programme Director for Conservation Finance
	Sheikha Ahmed Mohamed	Director General, Zanzibar Maritime Authority
	Rajab Moses	Director Port and Shipping, Zanzibar Maritime Authority
UK	Gwilym Rowlands	University of Oxford
Zambia	Edith Tibahwa	Programme Manager of Climate Change Unit, Common Markets for Eastern and Southern Africa (COMESA), Lusaka
Djibouti	Zacharia Kingori	Intergovernmental Authority on Development (IGAD), IGAD Secretariat

1. INTRODUCTION

1.1 Background

In their simplest form - 1st generation ports - ports operated in areas of uncontested spaces, benefiting from marine environments in which they could be situated safely and cost-effectively without competition (Kaliszewski 2018; Lee et al. 2018). However, with growing global trade, rapid coastal urbanization, depletion and degradation of natural resources, along with increasing expectations from stakeholder and greater social empowerment and awareness, there is a growing demand and accelerated quest for port sustainability. Ports are increasingly being pressurised to take actions, not merely focussing on economic objective, but also to include resilient sustainable strategies pertaining to the environment and society (Lu et al. 2016; Alamoush et al. 2021). The port industry therefore faces a growing challenge to address societal and environmental considerations while at the same time to improve their capacity to provide cost-effective services to traders (e.g., working towards 5th generation ports) (Kaliszewski, 2018; Lam and Van der Voorde, 2012; Roh et al., 2016). With increasing societal and regulatory pressures port authorities around the world are compelled to pursue greater sustainability to safeguard their 'license to operate' and to grow their economic and environmental competitiveness (Lam and Van der Voorde, 2012; Roh et al., 2016). In response to these global challenges the concept of 'Green Ports' has emerged, focusing on balancing environmental challenges and economic demand (Bergqvist and Monios 2019; Lam and Notteboom 2014) and striving for sustainability through increasing both economic and environmental competitiveness (Maritz et al. 2014). The concept of 'Sustainable Port Development' builds on that of 'Green Ports' by also considering social sustainability, in essence advocating the need for a port development to create a balance between economic growth, environmental protection, and social progress to secure its long-term future (Hiranandani 2014; Taljaard et al. 2021).

According to the World Bank (2017) sustainable Blue Economy is the '*sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem'.* It therefore strives *"to promote economic growth, social inclusion, and the preservation or improvement of livelihoods while at the same time ensuring environmental sustainability of the oceans and coastal areas"*. Aligned with this description the *Africa Blue Economy Strategy* (AU 2019) views the Blue Economy as '*an inclusive and sustainable economy that becomes a significant contributor to continental transformation and growth, through advancing knowledge on marine and aquatic biotechnology, environmental sustainability, the growth of an Africa-wide shipping industry, the development of sea, river and lake transport, the management of fishing activities in these aquatic spaces, and the exploitation and beneficiation of deep sea mineral and other resources'*.

The Western Indian Ocean (WIO) region is currently experiencing an unprecedented growth in large-scale development which includes ports, mining, roads and railways, agriculture, and oil and gas, all principally driven by large infrastructure demands and financial inflows from different funding streams. Economic growth and development are inevitable if countries of the WIO region want to address social challenges such as poverty and inequality. Most of these developments are concentrated in coastal areas which support rich natural resources. The region has an opportunity to define sustainable trajectories for these investments, but development also has the potential to significantly impact the integrity of critical habitats and the natural resource base that future growth and societal well-being depends on. In the WIO Region coastal communities are especially reliant on coastal resources for their lives and livelihoods. Considering the rich diversity of coastal and marine ecosystems in the WIO region, and its potential to contribute to socio-economic benefits, Blue Economy growth holds great promise for the area.

Several initiatives in the WIO region have already started to adopt sustainable port initiatives, including:

- Kenya Ports Authority (KPA) has adopted a Green Port Policy (GPP) that is intended to address the negative impacts of port operations and is geared towards integration of environmental sustainability in port development/operations and significant reduction in greenhouse gas emissions. The policy focuses on initiatives on climate change mitigation/adaptation, use of renewable energy and recognizes the importance of stakeholders and partners towards achieving its sustainability objectives. Currently, the focus of the GPP is on the Port of Mombasa, but the KPA plans to expand its scope to include other ports managed by them, including the Ports of Lamu and Kisumu, and the dry ports.
- The Port of Maputo is implementing initiatives to reduce the emission of greenhouse gases. Currently tugs and pilot boats turn off their generators when moored and electricity is supplied by sources installed on the pier. The Maputo Port Development Company (MPDC) is also undertaking restoration of forests and tree planting.
- The government of Tanzania, through the Tanzania Ports Authority (TPA), has been taking steps to improve port sustainability to protect the marine environment. In consultation with Royal HaskoningDHV and Deltares a Green Port Policy (2018) has been developed specifically aimed at greening both existing operations as well as the design, implementation, and operations of new infrastructures in the Port of Dar es Salaam.
- Madagascar's largest and main seaport, the Port of Toamasina, has been increasing its container reception and storage capacity, whilst still committed to environmental protection as per national law and adopting good examples from other countries 'going green'.
- In South Africa, sustainability and sourcing new and alternative energy sources has been one of Transnet National Ports Authority's (TNPA) goals in recent years. To this end the TNPA is embarking on the installation of solar technologies to alleviate the country's power challenges and to support greener operations in its ports. One such successful initiative is the greening of energy sources at lighthouses and other marine aids to assist with navigation of vessels within port limits and along the coast.
- The Seychelles Port Authority (SPA) has been engaging in several green port initiatives involving the development of a National Heritage Plan for Port Victoria, and an Environmental and Social Policy to be followed by the development of an Environmental Management System towards achieving ISO 14001 certification.
- Port Management Association East and Southern Africa (PMAESA) together with the Maritime Technology Cooperation Centre-Africa (MTCC-Africa) is in consultation to sign a memorandum of understanding on baseline energy audit surveys and establishing the extent to which ports in the region have embraced GPP.

1.2 Purpose

Building on these initiatives and complimentary to the *Strategic Framework for Coastal and Marine Water Quality Management in the Western Indian Ocean Region* (UNEP et al. 2022), this Nairobi Convention project seeks to facilitate sustainable port development in the WIO on request of the Conference of Parties (CoP). It is part of, and supports the *Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP)* Project, informed by the appreciation that ports intersect with critical coastal and marine resources, and aligned with the WIO region's vision to grow a sustainable Blue Economy.

Specifically, the contribution to sustainable port development in the WIO region includes:

- Situation Assessment providing the context and backdrop for greener port operations and development in the WIO region

- Scenario Analysis evaluating development options from 'business as usual' to options incorporating environmental considerations ('sustainable port' option) (UNEP et al. 2023a)
- Toolkit for Sustainable Port development in a Blue Economy comprising practical management and operational tools aimed at supporting port operators in the WIO region towards achieving sustainable port development in WIO region in the future (UNEP et al. 2023b)
- Policy Brief capturing proposed recommendations for future sustainable port development in the WIO region.

The science-based outputs generated from this project will be shared with national governments to support and guide them in the development of national policies for sustainable port development. Further, the outputs will be shared with port developers and operators in the region to support and guide them with the implementation of sustainable port development options. This will be achieved through the Science-to-Policy Platform supported by the Nairobi Convention.

This document presents the Situation Assessment, including:

- Overview of ports in the WIO regions, including legal instruments, as well as key objectives and responsibilities pertaining to environmental matters, where applicable
- International review on key environmental impacts and socio-economic consequences potentially associated with port development as is relevant to the WIO region
- Preparation of geo-referenced habitat mapping demarcating the location of major commercial ports in the WIO Region (operational, under construction and proposed), as well as important coastal marine ecosystems to be derived from available geospatial databases
- Introduction to the concept of Sustainable Ports.

1.3 Structure of this Report

This report presents the Situation Assessment towards sustainable port development in the WIO region and comprises of the following:

- Introductory chapter presenting the background and purpose of this study (this Chapter)
- Overview of location of documented (including proposed) ports and harbours in countries of the WIO region (Chapter 2)
- Overview of key legislation and authorities governing port development in the region (Chapter 3)
- Overview of the general environmentally related issues associated with port construction and operations relevant to the WIO region, as well as consequences to important socio-economic benefits derived from natural resources (Chapter 4)
- Detailed assessment of selected case studies using geo-reference mapping to demonstrate change encountered in important coastal and marine habitats because of port development in the region, and map a way forward for geospatial data generation (Chapter 5)
- Introduction to the concept of Sustainable Ports, highlighting the importance of balancing economic viability with environmental and social accountability, as well as the critical role of sound environmental practice in port development in achieving sustainability goals (Chapter 6).
- Finally, Chapter 7 summarises key outcomes and recommendations for consideration in the *Scenario Analysis* study, as well as in the *Toolkit for Sustainable Port Development in a Blue Economy* and the *Policy Brief.*

2. OVERVIEW OF PORTS IN WIO REGION

This chapter provides a brief overview of the seaports of countries in the WIO region (see Appendix A for detailed information). Several of these countries also support larger inland ports (in river systems and lakes) but these are not included in the overview.

2.1 Comoros

The Union of Comoros has two containerized ports located in Moroni (Grande Comore Island) and Mutsamudu (Anjouan Island) (https://dlca.logcluster.org/; https://www.comorosmaritime.org) (Figure 2.1). The major port at Mutsamudu is a well-protected, deep-water port that can accommodate large ships. The Port of Moroni, situated in shallower waters, is less competitive as it cannot accommodate the docking of larger ships. Smaller ports are located at Fomboni (Moheli Island) and Mayotte, Longoni and Dzaoudzi (Mayotte Island).

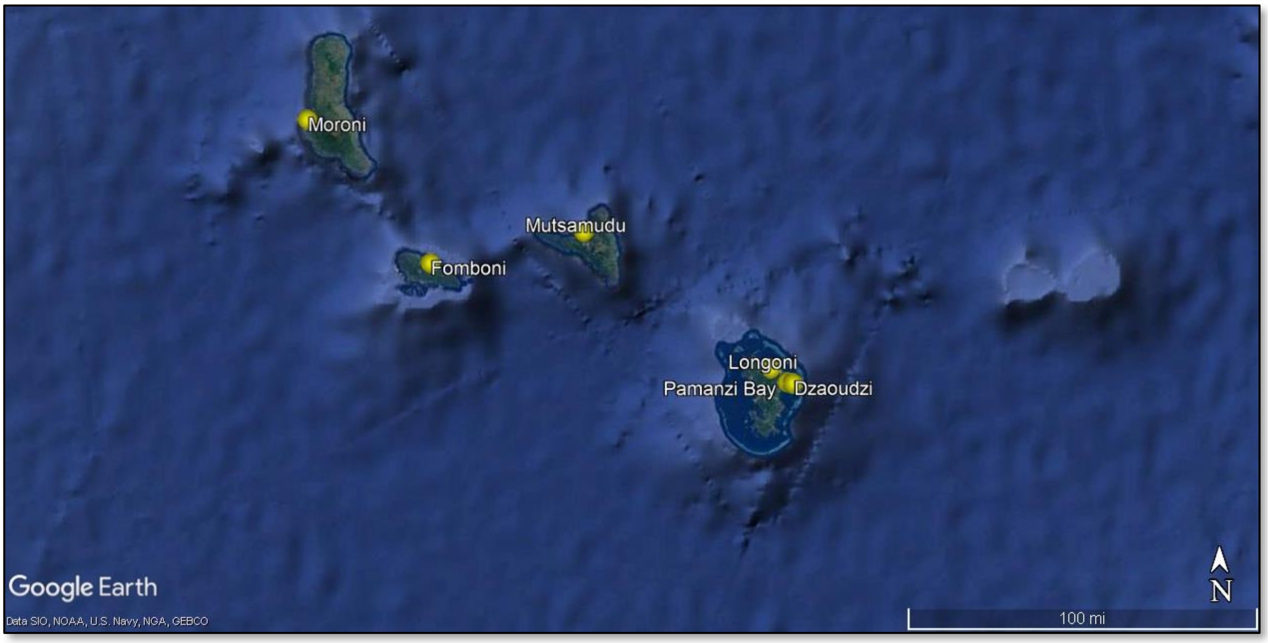

Figure 2.1 Location of documented ports in Union of Comoros (see Appendix A for more details)

2.2 Kenya

The Port of Mombasa is currently the main commercial port in Kenya (https://kpa.co.ke/) and is a national and regional facility of great significance serving as the key entry port to Kenya, Uganda, Rwanda, Burundi, South Sudan, Northern Tanzania, and Eastern Democratic Republic of the Congo. It also has handles cargo for Ethiopia and Somalia. The Port serves over 33 shipping lines and provides connectivity to over 80 seaports worldwide. Within the port, Kilindini Harbour, situated in a is a naturally deep and well sheltered area, is the main harbour where most of the shipping activities take place. The existing infrastructure and facilities at the Port of Mombasa comprises 21 berths including oil terminals (Kipevu and Shimanzi), as well as terminals handling passenger vessels, RoRo (Roll-on, Roll-off) and motor vehicles, bulk grain and dry bulk- clinker, general cargo and containers. Other facilities include wharfs that handles both oil and bulk dry bulk cargo and smaller jetties. Within the Port of Mombasa, new development is planned in the Dongo Kundu area (https://africaports.co.za/mombasa/).

The Port of Mombasa in Kenya is one of the busiest ports in East Africa, handling over 7 million tons of cargo per year. It is also a major hub of regional and international trade, with over 3,000 vessels visiting the port each year. It has been an important hub of maritime trade since the 16th century. The earliest known reference to the port dates to the 16th century when it was visited by Portuguese explorer Vasco da Gama. During the 16th and 17th centuries, the Port of Mombasa was a major trading port for the Portuguese and was heavily fortified. In the late 18th century, the British East India Company became involved in the port, and began to develop it as a major trading hub. This included the construction of a new dockyard, and the introduction of steam-powered vessels. In the 19th century, the port was further developed, with the construction of new warehouses and a maritime college.

In the early 20th century, the port underwent further modernization, with the construction of a new port and the introduction of modern cargo handling facilities (Figure 2.2). Since the 1950s, the Port of Mombasa has gone through several development phases. In the 1970s, the port was expanded and modernized, with the introduction of new container handling facilities and a new container terminal. In the 1990s, the port was further developed, with the construction of a new passenger terminal and the introduction of new oil tanker facilities (UNEP et al. 2021).

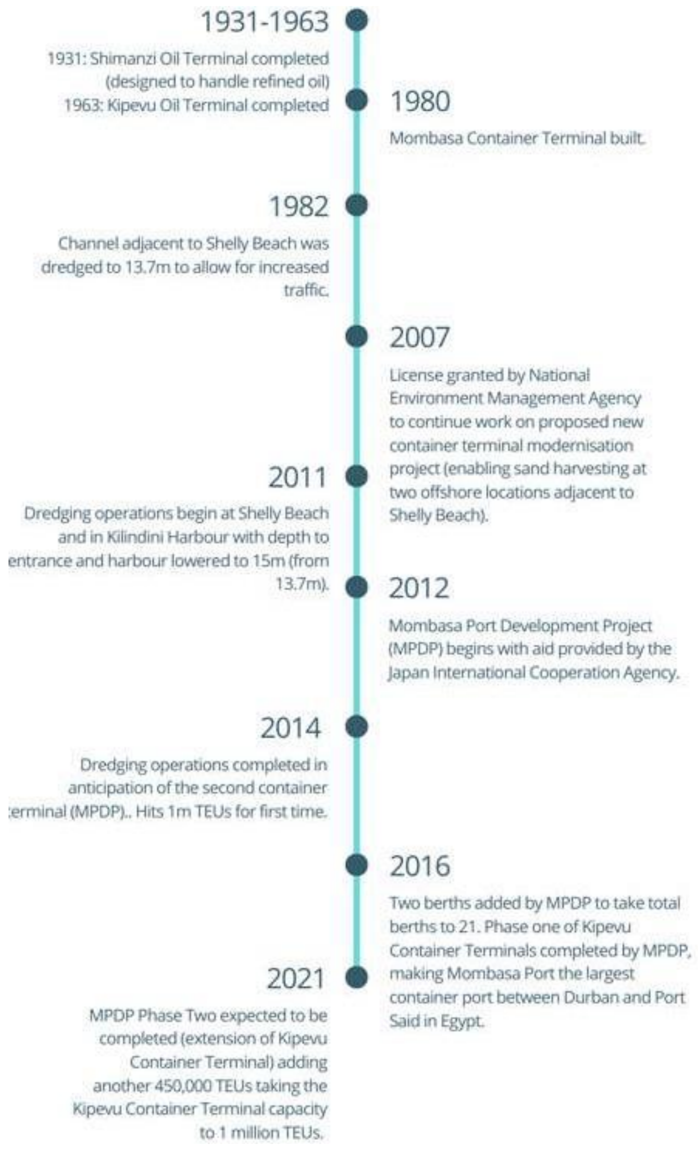

Figure 2.2 Major Development Milestones at Mombasa Port from 1931-2021 (Source: UNEP et al. 2021)

The Kenyan government has invested heavily in the port over the past two decades and since 2000 the port has experienced substantial development. This growth has been driven by numerous government initiatives and international investments. This investment has included the construction of new berths, the improvement of existing infrastructure, and the purchase of new equipment. This has allowed the port to expand its capacity and handle an increased amount of cargo. In addition, the government has sought to reduce the time it takes for goods to be unloaded at the port. As a result, the port is now capable of handling larger ships and has become more efficient. International investments have also been a major factor in the port's development. In 2018, the Chinese government provided a loan of $3.4 billion for the expansion of the port, which allowed for the construction of new berths. This has enabled the port to handle larger vessels, increase its cargo capacity.

Figure 2.3 Location of documented ports in Kenya (see Appendix A for more details)

The construction of the new Port of Lamu is one of the flagship infrastructure projects of Kenya's Government Vision 2030 to develop a new transport corridor and becoming second largest seaport in Kenya acting as a regional transport hub and the biggest deep-sea port in East Africa when completed (www.kpa.co.ke/OurBusiness/pages/lamu.aspx). It has a sheltered bay and a wide navigable entrance. Its 10 km shore has the capacity to accommodate up to 23 berths. The first phase of the port, consisting of three 400 m berths have been completed and became partially operational in 2021 focus on transhipment cargoes. Other small seaports are located at Vanga, Shimomi, Funzi, Mtwapa, Kilifi, Malindi and Kiunga (www.kpa.co.ke/OurBusiness/Pages/Small-Ports.aspx) (Figure 2.3). A larger fishing port is planned for Shimoni, while Ngomeni and Takaungu also have been considered for future port development.

2.3 Madagascar

Madagascar has a network of 17 seaports including Toamasina, Antsiranana, Nosy Be, Mahajanga, Toliara, Antalaha, Vohémar, Morondava, Tolagnaro, Morombe, Manakara, Maintirano, Sainte Marie, Maroantsetra and Antalaha (Figure 2.4) (Two other in rivers - Port Saint Louis and Antsohihy).

Five of these ports (Antsiranana, Toliara, Vohémar, Toamasina, Tolagnaro) have adequate port facilities, allowing for commercial loading and unloading of goods (https://dlca.logcluster.org/). Major expansions are planned at Tamatave where trade is expected to triple after full delivery of the port extension in 2025 (www.lejournaldesarchipels.com/2021/05/13/port-of-tamatave-an-extension-to-640-million-dollars/?lang=en).

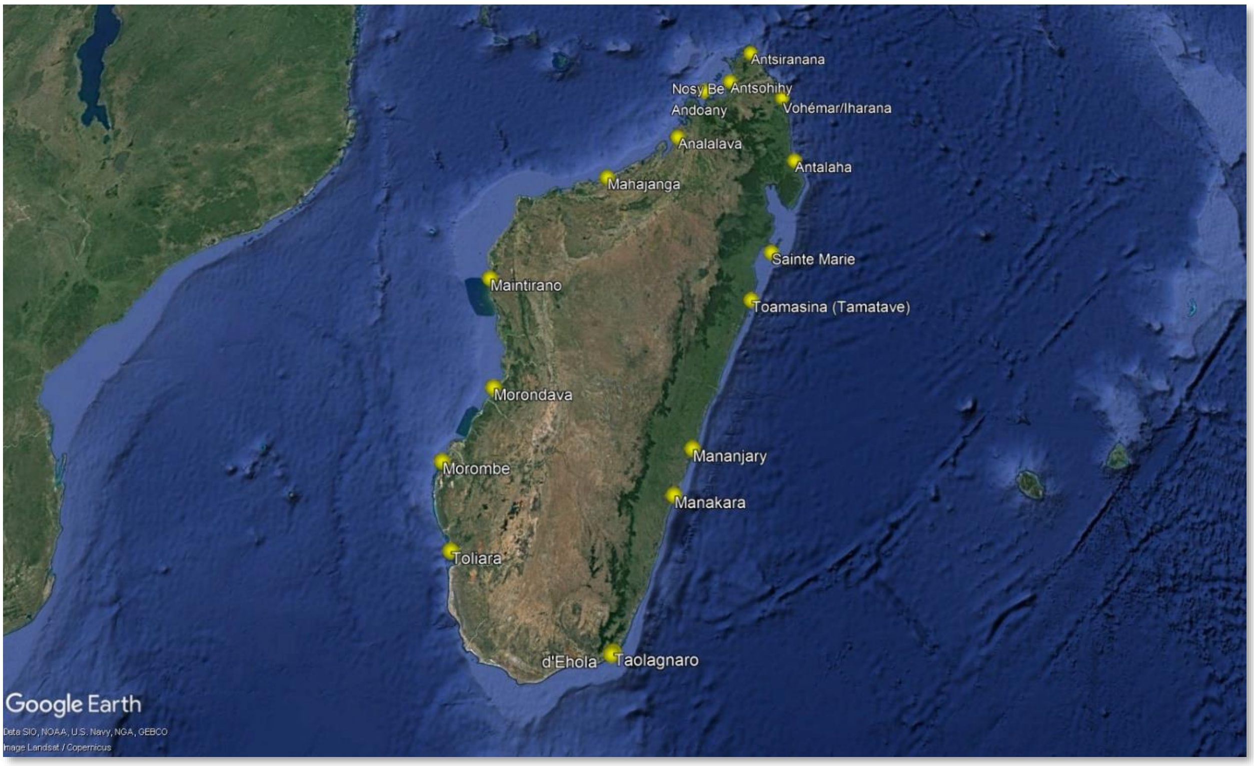

Figure 2.4 Location of documented ports in Madagascar (see Appendix A for more details)

2.4 Mauritius

Mauritius has two ports, namely Port Louis (main island) and Port Mathurin (Rodriques) Figure 2.5, Table 2.1). No new ports are either proposed or planned for Mauritius.

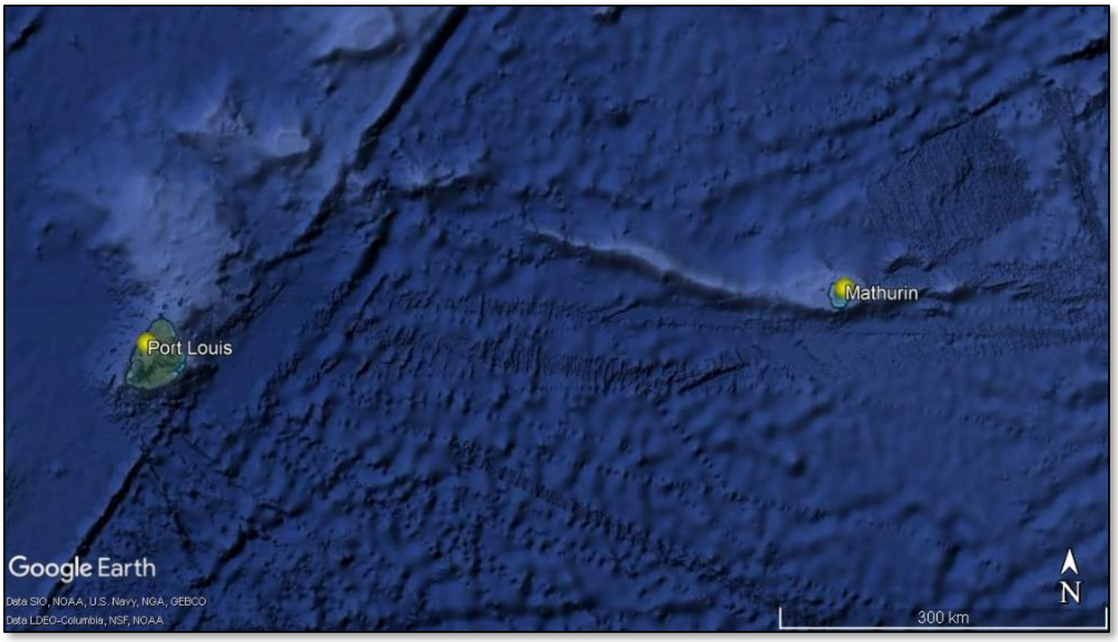

Figure 2.5 Location of documented ports in Mauritius (see Appendix A for more details)

2.5 Mozambique

Mozambique has three main ports at Maputo (along southwestern coast), Beira (central coast) and Nacala (northern coast) (Figure 2.5). The Port of Maputo is the largest and most developed port in Mozambique comprising two terminals, that is Maputo and Matola. Terminals at Maputo include bulk cargo, general cargo, containers, magnetite and coal, sugar, vegetable oil and molasses, while terminals at Matola handle coal, jet oil, cereals and aluminium.

The Port of Maputo also serves southern African hinterland countries including eSwatini (Swaziland), Zimbabwe, South Africa, and Botswana. The Ports of Nacala and Nacala-à-Velha is the largest deep-water natural harbour on the East African Coast. The Port of Nacala serves as export terminal for cargo via railway from Malawi, as well as the cities of Nampula, Lichinga and Moatize in Mozambique.

Secondary ports include the Ports of Inhambane, Quelimane, Angoche, Pemba, and the newly constructed Port of Palma (along north coast) newly constructed in the North of Mozambique). Other smaller ports exist at Ibo, Mocambique and Pebane (Figure 2.6) (https://dlca.logcluster.org/). The planned new deep water port at Macuse in the Zambézia province, to assist with coal exports, is currently considered to commence in August 2023 (https://clubofmozambique.com/news/macuse-logistics-corridor-still-no-date-for-the-start-of-railway-line-works-carta-222713/).

Figure 2.6 Location of documented ports in Mozambique (see Appendix A for more details)

2.6 Réunion (France)

The main commercial Port of Reunion, Port Réunion, comprise Ouest Port (old port) and Est Port (new port). A smaller port, Port de Sainte-Marie is in the north of the island in a marina development (Figure 2.7).

Figure 2.7 Location of documented ports in Réunion (see Appendix A for more details)

2.7 Seychelles

Port Victoria is the main multi-purpose port of the Seychelles situated on the Island of Mahé. The types of vessels regularly calling at this port include Fishing Vessel (24%), Fishing (19%), Sailing Vessel (11%), Pleasure Craft (11%), Container Ship (6%) (http://www.seyport.sc/) (Figure 2.8). Various terminals have been constructed in the port to facilitate international and domestic trade. On the main island of Mahe, there are six facilities under SPA's responsibility namely the Mahe Quay, Industrial Fishing Port, Inter-Island Quay (domestic cargo and passenger terminal), EU Quay, IPHS (private port) and Bel Ombre. On Praslin, the Seychelles Port Authority (SPA) is responsible for the Baie Ste Anne Jetty (domestic passenger terminal), Eve Island Cargo terminal (domestic cargo terminal) and Eve Island Annex Passenger terminal (quay completed in 2020 and passenger terminal is in construction). On La Digue the SPA also manages the La Digue port/jetty.

Figure 2.8 Location of documented ports in Seychelles (see Appendix A for more details)

A major extension and rehabilitation project has been planned at the Mahe Quay, while a project is underway since March 2022 to extend the jetty and deepen the turning basin at La Digue (project is expected to be completed in March 2023). It is worth noting that there are other port facilities that do not fall under SPA's responsibility. These are mostly fishing ports managed by the Seychelles Fishing Authority (SFA).

2.8 Somalia

The main ports of Somalia are situated at Mogadishu, Kismayo, Bossaso, and Berbera (Somaliland) (Figure 2.9 and Table 2.1) (somalitalk.com/2010/may/istambul/transport.pdf). Smaller ports (or jetties) are located El Maan, Lughaya, Alula, Hafun, Eyl, Gracad, Hobyo, Merca, Qandala, and Maydh and Las Khorey (Somaliland).

Figure 2.9 Location of documented ports in Somalia (see Appendix A for more details)

2.9 South Africa

South Africa has eight commercial ports situated at Richards Bay, Durban, East London, Port Elizabeth, Ngqura, Mossel Bay, Cape Town and Saldanha. The ninth port at Port Nolloth (west coast), does not handle any commercial cargo and is leased to De Beers Consolidated Diamond Mines. In addition, there are numerous smaller harbours located along South Africa's coast (Figure 2.10). Two commercial ports are proposed, that is a deep-water port at Durban and another at (east coast) and Boegoebaai (west coast). Three of the current commercial ports are in the WIO region, namely the Ports of Richards Bay, Durban, and East London.

The Port at Richards Bay handles more than 100 million tonnes of cargo annually, making it the leading port in the country in terms of volumes. It is also the largest in South Africa with a total area of 3,773 hectares (2,026 hectares of land and 1,746 hectares of water area). The port has six cargo handling terminals, including a dry bulk terminal for imports and exports of ores, minerals and woodchips, a multi-purpose terminal for break-bulk cargo, including ferrochrome, pig iron, steel, forest products, granite, aluminium, bagged cargo, containers, heavy and abnormal loads, and one of the largest export coal terminals in the world with a current capacity to export 75 million tonnes per annum, as well as a chemical tank farm for liquid bulk products stored in tanks. The Port of Durban covers an area of 1,854 hectares with 58 berths and over 3900 commercial vessels call at the port each year. The Port of Durban is the country's main general cargo, bulk liquid, and container port. It has two dedicated container terminals and two separate facilities that handle automobiles and petrochemicals respectively.

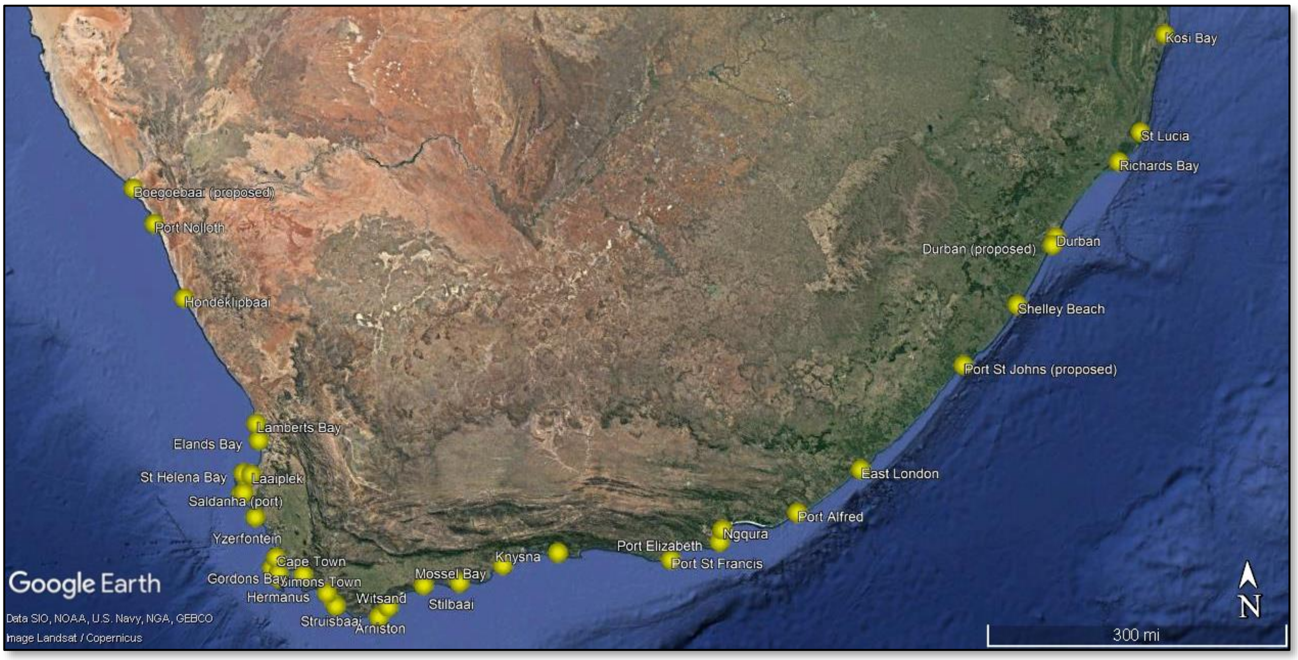

Figure 2.10 Location of documented ports in South Africa (see Appendix A for more details)

Durban's port also has a dry-dock for ship repair. The East London Port specialises in servicing the automotive industry and has a modern automotive terminal (with real time tracking and monitoring of units) that is linked directly to an adjacent automobile production plant through a private road and bridge that was commissioned by the port. There are a total of eleven commercial berths that offer container, automotive, break-bulk, bulk grain and bulk liquid (refined petroleum products) handling facilities. This port also is serviced by a national rail network system providing access to all major cities within the borders South Africa and neighbouring states. In addition, the East London Port also has a dry-dock for vessel repairs and maintenance.

2.10 Tanzania

The gateway port in Tanzania is the Port of Dar es Salaam. The port has a total quay length of 2.6 km. There are 12 berths at the main quay, as well as a single buoy mooring (SBM) and a dedicated berthing area for coastal vessels at the lighterage quay. Other major ports are situated at Tanga and Mtwara (www.ports.go.tz/index.php/en/). Smaller seaports are situated at Kilwa, Lindi, Mafia, Pangani and Bagamoyo (dlca.logcluster.org/) (Figure 2.11). Another ten minor ports are also located along the Tanzanian coast. A major new port development (green field) at Bagamoyo is again considered (https://www.thecitizen.co.tz/tanzania/news/national/foreign-firms-eye-tanzania-s-sh23-trillion-bagamoyo-port-3924900).

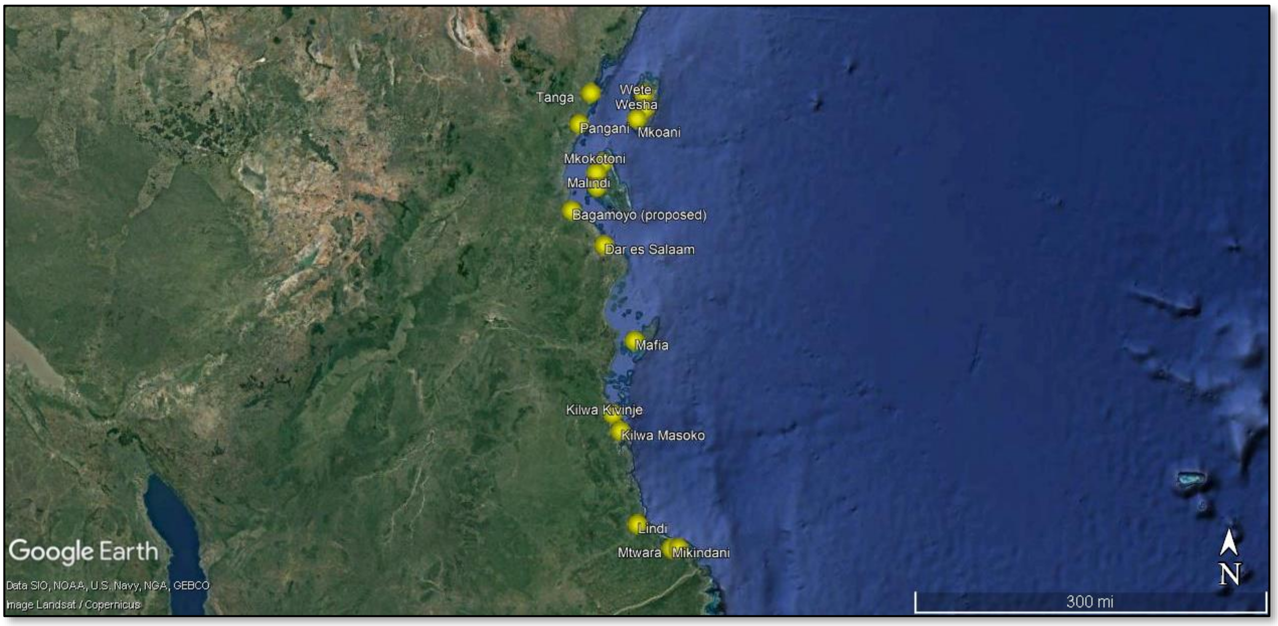

Figure 2.11 Location of documented ports in Tanzania (including Islands of Zanzibar) (see Appendix A for more details)

The Port at Malindi is the main port on the Islands of Zanzibar (Unguja), with smaller ports at Mkokotoni (Ynguja), and Wete, Wesha and Mkonani (Pemba) (https://zpc.go.tz/). A new multi-purpose port is also planned at Mangapwani (Unguja) to meet the growing trading target for Zanzibar (https://www.dar.com/work/project/mangapwani-multipurpose-port).

3. OVERVIEW OF KEY LEGISLATION & AUTHORITIES

3.1 International and Regional Conventions & Agreements

Several countries in the WIO region are signatories to international conventions or agreements to combat and prevent environmental impact directly linked to shipping activities and which may also apply in ports (Table 3.1).

Table 3.1: Key International and regional conventions/agreements directly linked to combat and prevent environment impact directly linked to shipping activities, indicating signatory countries

CONVENTION/ AGREEMENT	DECRIPTION	Comoros	Kenya	Madagascar	Mauritius	Mozambique	Reunion (France)	Seychelles	Somalia	South Africa	Tanzania
International Convention on Civil Liability for Oil Pollution Damage (CLC) (1969, enforced 1975), replaced by 1992 Protocol (1992, enforced 1996)	ensure that adequate compensation is available to persons who suffer oil pollution damage resulting from maritime casualties involving oil-carrying ship - https://www.imo.org/en/About/Conventions/Pages/ListOfConventions.aspx	●	●	●	●	●	●	●		●	●
International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties (INTERVENTION) (1969, enforced 1975)	Affirms right of coastal states to measures on high seas to prevent, mitigate or eliminate danger to its coastline or related interests from pollution by oil or threat thereof, following upon a maritime casualty				●		●			●	●
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972) and London Protocol (1996)	Prohibiting dumping of certain hazardous materials. In addition, a special permit is required prior to dumping of several other identified materials and a general permit for other wastes or matter		●				●	●		●	●
	1996 Protocol to Convention prohibits all dumping, except for possibly acceptable wastes on the so-called 'reverse list'		●	●						●	
International Convention for Prevention of Pollution from Ships (MARPOL) (1973)	Main international convention covering prevention of pollution by ships from operational or accidental causes:										
	Annex I: Regulations for the Prevention of Pollution by Oil	●	●	●	●	●	●	●	●	●	●
	Annex II: Control of Pollution by Noxious Liquid Substances	●	●	●	●	●	●	●		●	●
	Annex III: Harmful Substances Carried by Sea in Packaged Form	●	●	●	●	●	●	●		●	●
	Annex IV: Sewage from Ships	●	●	●	●	●	●	●		●	●
	Annex V: Garbage from Ships	●	●	●	●	●	●	●		●	●
	Annex VI: Air Pollution from Ships		●	●	●		●	●		●	
United Nations Convention on the Law of the Sea (UNCLOS) (1982)	This convention is cornerstone of ocean governance at the national, regional, and global levels. Section 5 addresses prevention of pollution of the marine environment - www.iucn.org/theme/marine-and-polar/our-work/international-ocean-governance/unclos	●	●	●	●	●	●	●	●	●	●
Regional Seas Programme: Nairobi Convention (1985, enforced 1996)	Partnership between governments, civil society, and private sector, working towards a prosperous Western Indian Ocean Region. This Convention offers a regional legal framework and coordinates efforts of member states to plan and develop programmes that strengthen their capacity to protect, manage and develop their coastal and marine environment - https://www.nairobiconvention.org/nairobi-convention	●	●	●	●	●	●	●	●	●	●

CONVENTION/ AGREEMENT	DECRIPTION	Comoros	Kenya	Madagascar	Mauritius	Mozambique	Reunion (France)	Seychelles	Somalia	South Africa	Tanzania
International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) (1990, enforced 1995)	Require parties to establish measures for dealing with pollution incidents, either nationally or in co-operation with other countries	●	●	●	●	●	●	●		●	●
International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND) 1992 Protocol (1992, enforced 1996)	Under this Convention, victims of oil pollution damage may be compensated beyond level of ship owners' liability	●	●	●	●	●	●	●		●	●
International Convention on Civil Liability for Bunker Oil Pollution Damage (BUNKER) (2001, enforced 2008)	The Convention ensures adequate, prompt, and effective compensation availability to persons who suffer damage caused by spills of oil, when carried as fuel in ships' bunkers	●	●	●	●		●	●			
Stockholm Convention (2001, enforced 2004)	Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from chemicals that remain intact in the environment for long periods - http://www.pops.int/	●	●	●	●	●	●	●	●	●	●
International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) (2004, enforced 2017)	This Convention aims to prevent spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for management and control of ships' ballast water and sediments		●	●			●	●		●	
2030 Agenda for Sustainable Development (2015)	Adopted by UN member states as an agenda for people, planet, and prosperity. Seventeen Sustainable Development goals were identified of which some are relevant to marine pollution prevention (www.un.org.za/sdgs/2030-agenda/)	●	●	●	●	●	●	●	●	●	●

Agenda 2030 and its Sustainable Development Goals (SDGs) have a central, overarching aim of ensuring environmentally sustainable and socially equitable development, including in ports. Indeed, it has been argued that holistic port sustainability actions, when addressing environmental, social and economic interventions can contribute significantly to achieving the UN SDGs due to some commonality in addressing the Triple bottom line (Alamoush et al. 2021).

Regionally, the Nairobi Convention also aims to address the accelerating degradation of the marine environment in the WIO region through sustainable management and use of resources by those sharing these environments. Regional initiatives that may also pertain to the prevention and combating of impacts from ports, include:

- Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP)
- Protocol for the Protection of the Marine and Coastal Environment of the Western Indian Ocean from Land-Based Sources and Activities (LBSA Protocol)
- Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms (SAPPHIRE)
- African, Caribbean, and Pacific (ACP) Countries Capacity Building of Multilateral Environmental Agreements project (MEAS).

3.2 Country-based Arrangements

3.2.1 Comoros

The National Agency for Maritime Affairs (ANAM) is the state body responsible for regulating maritime issues directly under the jurisdiction of the Ministry of Transport, Posts and Telecommunications. It has the mission of public service and the authority to develop and operate the international maritime registry of the Union of Comoros. The Port Authority of the Comoros (APC) is the authority responsible for designing the legal framework (establishment of concessions) and regulating port activities (wharf access, security, etc.) in the country (https://dlca.logcluster.org/).

The Port of Moroni's formal regulatory body in the APC is the Société Comorienne des Ports (SCP) created in 2013. However, the establishment of SCP has not yet been implemented, so the APC is still responsible for executing policies on the island of Grand Comoros. Bolloré Africa Logistics oversees the Moroni Terminal, which handles container and general cargo operations inside the Port of Moroni (Humphreys et al. 2019).

Environmentally related challenges pertaining to the Port of Moron, as derived from the National Five-Year Plan for Accelerated and Sustainable Growth included (Humphreys et al. 2019; World Bank 2018):

- Little specific attention given to infrastructure in port, one of the four defined axes of sustainable development (World Bank 2018)
- No specific attention given to environmental considerations in rehabilitating or developing port infrastructure
- No adequately distinguish between public and private sector responsibilities in terms of management, operations, or financing.

3.2.2 Kenya

The Kenya Ports Authority (KPA) trace its history back to 1967 when the East African Community (EAC) formed by Kenya, Tanzania and Uganda created the East African Harbours Corporation consisting of East African Harbours, East African Cargo Handling Services and East African Railways to run the principal Ports of Dar es Salaam, Mombasa and the oil port of Tanga. The corporation was dissolved 1977 and the individual countries went on to set up its own institutions. In Kenya the Ports Authority (KPA) was established under the Kenya Port Authority Act (Chapter 391 of laws of Kenya) in 1978 (https://www.kpa.co.ke/). The Kenya Cargo handling company, which was separately established in 1978 to provide stevedoring services to the Port of Mombasa later merged with KPA to form a single body responsible for all aspects of national port planning and operations.

KPA is mandated to develop, maintain, operate, improve, and regulate all seaports along the Kenyan Coast and Inland waterways in Kenya. The Authority is also in charge of dry Ports or Internal Container Deports (ICDs) in Nairobi, Naivasha, Kisumu and Eldoret. The Kenya Ports Authority Act providing regulatory powers to KPA to:

- Maintain, operate, improve and regulate the ports
- Construct, operate and maintain beacons and other navigational aids
- Construct new ports
- Carry out the business of stevedore, wharfinger or lighterman
- Store goods whether such goods have been or are to be handled as cargo or carried by the KPA
- Consign goods on behalf of other persons to any places whether within Kenya or elsewhere

- Provide such amenities or facilities for persons making use of the services performed or the facilities provided by the Authority as may appear to the Board necessary or desirable.

The Port of Mombasa complies with the provisions of MARPOL Convention with respect the provision of facilities for the reception of sludge, oily bilge waters, oily mixtures and other residues that cannot be discharged to sea. The current arrangement is that shipping lines make private arrangements with the private licensed port contractors. The port plays a crucial role in terms of port access, supervision of waste collection inside the port to prevent marine pollution and ensuring compliance to the licensing requirements of the Environmental regulator.

As part their rules and regulations for the Port of Mombasa the KPA specifies the following on the environment (www.kpa.co.ke/InforCenter/Pages/Health-and-Safety.aspx):

- Cleanliness is observed while in port
- Litter placed in litterbins provided
- No pollution to atmosphere, land, and marine environment
- No interference or destruction of flora and fauna
- No indiscriminate disposal of wastes including human/animal in yards and other open spaces and housing estates.

In 2017, the KPA adopted a Green Port Policy (GPP) at the Port of Mombasa to improve biodiversity protection. As a result, all ships arriving at the port will be required to convert to electric power instead of diesel engines. This initiative will guide future evaluation towards meeting international standards on sustainable ports (https://knowledge-hub.circle-lab.com/wctd/article/8057). The GPP provides a pro-active and comprehensive approach to address the negative environmental impact of port activities and operations focusing on green initiatives, emission reduction and guidance on environmentally friendly port planning and operations. Several programmes have been undertaken towards implementation of the Green Port Policies, including:

- Development of integrated Environmental Management Systems (EMS) - ISO: 14001 2015 Occupational Health and Safety Management System– ISO 45001: 2018
- Biodiversity protection and forestry programmes focusing on degraded coastal areas
- Development of a Strategic Waste Management Plan for the Port of Mombasa
- Acquisition of environmentally friendly and energy efficient cargo handling equipment
- Comprehensive analysis and study on port Energy needs, alternative energy sources with focus on renewable energy. Implementation of recommended energy efficiency measure are ongoing.

In recognition of the potential environmental and social Impacts of major infrastructural project especially port projects, KPA has subjected all the major development and expansion projects to a comprehensive Environmental and Social Impacts Assessment studies with extensive stakeholder engagement as a key element of the studies before has commencements of the projects. Periodic Environmental auditing also been a key tool in evaluating the environmental performance of existing ports facilities, operations and activities. The nature and location of the port expansion projects and the has also necessitated the need to carry out other assessments, including:

- Heritage Impact Assessments,
- Cumulative Impact Assessments
- Livelihood Restoration plans
- Fisheries surveys
- Resettlement plans for the project affected parties.

Some of the main strategic environmental objectives of ports planning and operations in Kenya include:

- Integrating environmental, social, safety and health concerns as priority issues in all ports and infrastructural development and operations
- Ensuring that development of port infrastructure causes minimum damage by incorporating integrated environmental and social impact assessments as a key requirement in ports projects and implementing mitigation measures
- Promoting energy conservation and environmental protection
- Encouraging the efficient and cost-effective use of fuel in port operations
- Developing energy conservation policies and programs including importation of high efficiency ports equipment and machinery which will reduce the level of emission
- Initiating and implementing green energy projects especially investments on renewable energy
- Creating environmental awareness and promoting inter-agency and stakeholder coordination in ensuring environmental conservation and protection.

3.2.3 Madagascar

Madagascar ports are classified as Ports of Regional Interest (PIR) and Ports of National Interest (PIN) Ports of Regional Interest are managed by the Agence Portuaire Maritime et Fluviale (Maritime and River Port Agency) (APMF) (https://www-apmf-mg). The APMF is the authority responsible for implementing the general policy of the State according to the strategies adopted by the Ministry of Transport concerning the port, maritime and river sub-sector, established under Decree No. 2003-659 (4 June 2003). The APMF ensures:

- Administration of port, maritime and river affairs
- Maritime and river "security and safety"
- Port licensing authority, supervision, and control of autonomously managed ports
- Regulation and management of public port, maritime and river areas
- Protection of the coastline and the marine environment
- Development and promotion of the sub-sector.

Priority actions in port include:

- Upgrade port infrastructure and establishment of maritime signalling
- Rehabilitate degraded infrastructure
- Bring Madagascar's international ports to International Ship and Port Security (ISPS) standards
- Carry out the institutional reforms of the ports in accordance with State policy
- Provide Madagascar with a master plan for ports
- Port management and operation

Ports of National Interest (PIN) are subject to two management methods, namely (https://www-apmf-mg):

- Autonomous management mode – 'Autonomous Management Ports' (PGA)
- Non-autonomous management mode with global concession, hence the term 'Ports à Concession Globale' (PCG).

Madagascar is currently in the final phase of the development of its National Port Master Plan.

3.2.4 Mauritius

The Mauritius Ports Authority (MPA) set up under the Ports Act of 1998, is the sole governing authority to regulate and control the port sectors in the Republic of Mauritius, including Rodrigues and all outer islands (Humphreys et al. 2019; http://www.mauport.com/). Acting as a landlord port authority, it provides the main port infrastructure and superstructure, together with related facilities, marine services, and navigation aids.

It also regulates and controls all port activities and environmental issues within the designated port areas. Currently, Port Louis Harbour is the only maritime gateway of the island.

As per section 5 of the Ports Act of 1998 the MPA shall periodically prepare and update its Port Master Plan that will define the framework and strategies for future port development. In this context the last Port Master Plan was completed in 2016. The Port Master Plan Study focused on new opportunities offered by activities related to the Ocean Economy and provided the land use planning for future port development projects. The Port Master Plan included an environmental scoping study to ensure sustainable development of the port. Furthermore, the plan also covered the risk aspects related to present and future port projects, emergency response planning and environmental protection. In view of the dynamic changes being observed in the maritime and port sector the MPA intends in the near future to embark on a new Port Master Plan that will identify new strategies for a sustainable growth and resilience of the port sector.

The Port Sector in Mauritius is regulated under the Ports Act of 1998 and the Port (Operations & Safety) Regulations 2005. The Act defines the role and powers of the Authority and its functioning. While the legislation defines the regulatory framework under which the port sector shall operate it also includes provisions for the conservancy and environmental protection of the harbour waters.

Port (Operations & Safety) Regulations 2005 on the other hand is a more prescriptive set of regulations that aim at ensuring that the required safety and environmental standards are being complied with regards to cargo handling operations and maritime activities.

3.2.5 Mozambique

Mozambique Ports and Railways (CFM), a legally constituted state-owned company is responsible for the operations of port and railways and was established through Decree Nr 40/94 (13 September 1994). The CFM views environmental management and protection as an important aspect in all its activities (https://www.cfm.co.mz/).

Maputo Port Development Company (MPDC) is a national private company that, in partnership with CFM, was given the concession for the management of the Port of Maputo. MPDC holds the powers of a Port Authority, being responsible for maritime operations, piloting, stevedoring, terminal, and warehouse operations, as well as port's planning development (https://www.portmaputo.com). The company has a Policy on Health, Safety and Environment and considers safety and environmental protection and management essential for sustainable future growth (https://www.portmaputo.com/policies-procedures/health-safety-environment/). To achieve this port authorities address, for example, education (internally and externally), environmental impact reduction, monitoring and management activities, innovation for the environment, CO_2 reduction, initiatives to reduce plastic in the oceans (https://www.portmaputo.com/sustainability/environment/).

In May 2022 the future sustainable vision for the future of the Port of Maputo presented as part of the new Master Plan that draws a roadmap for the Port of Maputo beyond 2043. Volumes ath this port is expected to grow to 42 million tonnes per year in 2033 and 54 million tonnes per year in 2043. Under the principles of Green Ports, Mozambique approved a Regulation for the Prevention of Pollution and Protection of the Marine and Coastal Environment. This Regulation establishes that all Ports in Mozambique must have appropriate reception facilities for collection and treatment of various types of waste and prevent pollution.

The Port of Beira, the second largest port in Mozambique, is managed by Cornelder de Moçambique (CdM) is a private consortium, formed through a partnership between CFM and the Cornelder Group (https://www.cornelder.co.mz/). Based on available literature, a port master plan for the Port of Beira in 2013, in partnership with Royal HaskoningDHV (Van der Meer 2013). Specifically, the master plan highlights potential environmental impacts of port operations and future expansions, mostly related to dredging activities (https://repository.tudelft.nl/islandora/object/uuid%3Aa2b85b0b-57eb-4eb5-b130-014c0be5b12f).

3.2.6 Réunion (France)

The Port of Reunion is managed by Grand Port Maritime de La Réunion (reunion.port.fr/en/homepage/#). A key priority of their 2019-2023 Strategic Plan, which was drawn up in accordance with article L.122-9 of the Environmental Code, is sustainability, and aims to position the port as a strategic player and driving force for sustainable development in the Indian Ocean (reunion.port.fr/en/our-commitments/). Since 2014, the port has adopted an environmental management system and structured monitoring through the Sustainable Development and Management Plan - reunion.port.fr/en/pa2d/), a Natural Heritage Master Plan (reunion.port.fr/en/nhmp/), as well as environmental monitoring of terrestrial and marine environments during development projects. This enables the authorities to manage natural and technological risk, industrial ecology, and environmental protection in the context global warming and conservation of biodiversity.

3.2.7 Seychelles

Since October 2020, the Ministry for Transport (MoT) holds the port portfolio. The Ministry is responsible for providing policy related decisions and strategy to the Seychelles Ports Authority (SPA). SPA is governed by a Board of Directors appointed every three years. SPA was established in 2004 by the SPA Act (2004) and as Public Enterprise (PE), SPA has the following responsibilities:

- Regulate, control and administer all matters relating to the safety and security of the port and its facilities
- Promote the development of the infrastructure relating to the port
- Maintain port installations and to promote the use, improvement and development of the port
- Encourage the use of reliable and sufficient equipment in the provision of port services
- Participate in matters pertaining to search and rescue
- Collect all harbour dues, rental fees and other moneys payable to the Authority under this Act or any other law
- Plan, execute, monitor and evaluate training programmes of employees designed to ensure conformity with the standards of the services provided by them
- Act in collaboration with other public authorities and entities for the prevention of marine source pollution, protection of marine environment and to respond to marine environment incidents
- Advise the government or any public authority on any matter relating to merchant shipping and the prevention and control of marine pollution
- Represent Seychelles on maritime matters at both the national and international level
- Do all such other things as will contribute to the attainment of the objectives of the Authority.

Currently the SPA Act (2004) is under review to ensure that is at par with international and regional conventions.

The initial Environment Impact Assessment for the Port Victoria Extension and Rehabilitation Project (PVREP) was conducted in 2015 and looked at all the possible impacts of the new proposed development on the environment. A supplementary environment and social impact assessment (ESIA) is currently being carried out specifically for the dredging works. The ESIA will also include an Environmental Management Plan and a dredging management plan. As a country that is highly regarded internationally for environment conservation, all the necessary precautions to prevent environmental damages are taken for all national projects, including all port development projects.

The SPA Strategic Plan 2018-2023 (http://www.seyport.sc/index.php/about/our-strategic-plan) establishes the overall direction for development of the ports sector as well as broader economic transformations considered crucial for efficient port functioning. As one of its strategic objectives (Objective 8), the SPA wants to gradually integrate Green Port Initiatives in their development plans that will contribute to better port environmental management and cost savings.

3.2.8 Somalia

The Ministry of Ports and Marine Transport (MPMT) is responsible for the promoting on sustainable development of maritime transportation sector in Somalia, modernisation of ports, improving associated socio-economic conditions, ensuring maritime safety, and protecting the marine environment (mpmt.gov.so/en/about-us/). They are set out to create and build an environment for blue ocean economic development through the establishment of policies and regulations to ensure and respond in terms of safety and security in maritime transport system, protecting marine environment. The ministry has ten departments and two agencies:

- Somali Port Authority
- Somali Shipping Line Agency.

The Marine Environmental and coastal Protection Department is responsible for the following duties (mpmt.gov.so/en/marine-environmental-and-coastal-protection-department/):

- Prevention of marine environmental pollution
- Promote and raise awareness on coastal environmental protection
- Implementing environmental policies and practice
- To ensure safeguard the natural marine environment
- Prepare for contingency plan for oil spill and other pollutants
- Mitigation and termination and for Oil spill and acute pollution of offshore and onshore
- Performs any other related duties assigned by Director General
- Ensuring compliance of international treaties and protocols in respect of protection of the marine environment.

The Port of Berbera is owned by the Somaliland Port Authority and Dubai Ports World (DP World) has a concession to operate the port (www.dpworld.com/news/releases/dp-world-and-somaliland-open-new-terminal-at-berbera-port-announce-second-phase-expansion-and-break-ground-for-economic-zone/).

According to Humphreys et al. (2019) coordinated strategic port plans (or master plans) still need to be prepared for Somalia (and Somaliland).

3.2.9 South Africa

Transnet National Ports Authority (TNPA), as prescribed in the National Ports Act (No.12 of 2005) (www.gov.za/documents/national-ports-act) is responsible for the safe, efficient, effective and economic functioning of the national ports system of the Republic of South Africa, which it manages, controls and administers on behalf of the Government. TNPA is the provider of port infrastructure and marine services at all eight fully operational commercial ports in the Republic of South Africa: Saldanha, Cape Town, Mossel Bay, East London, Port Elizabeth, Durban, Richards Bay and the Port of Ngqura. TNPA's business is divided into two key operational areas: port infrastructure and maritime operations. Port infrastructure and maritime operations (which includes dredging, navigation aids, ship repair and marine operations) are provided in five market segments: containers, dry bulk, liquid bulk, break-bulk and automotive. The major commodities handled at the ports are coal, iron ore, containers, automotives, steel, fruit, ferrochrome, petroleum products and manganese.

In South Africa, commercial ports are managed by the Transnet National Ports Authority (TNPA) (www.transnetnationalportsauthority.net/Pages/default.aspx). As prescribed in the National Ports Act (No.12 of 2005) (www.gov.za/documents/national-ports-act), it was created as a landlord port authority responsible for the safe, efficient, effective and economic functioning of the national ports system, which it manages, controls and administers on behalf of the Government. TNPA's business is divided into two key operational areas: port infrastructure and maritime operations. Port infrastructure and maritime operations (which includes dredging, navigation aids, ship repair and marine operations) are provided in five market segments: containers, dry bulk, liquid bulk, break-bulk and automotive.

Section 11 of the National Ports Act states that the main function of the TNPA is *"…to own, manage, control and administer ports to ensure their efficient and economic functioning, and in doing so the NPA must, amongst other aspects, regulate and control pollution and the protection of the environment within the port limits*". Section 69 of the Act elaborates on responsibilities related to environmental protection. Thus, legislation on commercial ports explicitly acknowledge the importance of pro-active integration of biophysical environmental aspects at all stages of port planning and operations, from the early stages of port planning and throughout the port development cycle including the planning, design, construction, operation and decommissioning. In March 2009, Port Rules were promulgated in terms of the National Ports Act. Chapter 4 for is devoted to measures pertaining to environmental protection (archive.opengazettes.org.za/archive/ZA/2009/government-gazette-ZA-vol-525-no-31986-dated-2009-03-06.pdf). A National Ports Plan has been developed for the commercial ports of South Africa by TNPA, as updated in 2019 (https://www.transnet.net/Divisions/Documents/NPP%202019.pdf).

Currently, in terms of the Government Immovable Asset Management Act (No. 19 of 2007) (GIAMA), the National Department of Public Works and Infrastructure is the custodian of the 12 proclaimed fishing harbours (Lamberts Bay, St Helena Bay, Saldanha Bay, Laaiplek, Hout Bay, Kalk Bay, Gordon's Bay, Hermanus, Gansbaai, Arniston, Struisbaai, and Stilbaai) and responsible for the infrastructure maintenance and repairs. The Department assigned certain responsibilities to Department of Forestry, Fisheries, and the Environment (DFFE) in terms of an MoU which mainly relate to operational regulation and management, including:

- Regulate licenses related to fishing
- Regulate permits and licenses related to operating marine craft
- Manage access into the harbour, basic landscaping, cleaning and security within the harbour and maintenance of up to R30 000
- Co-ordinate, advise and manage the implementation of harbour management directives, plans and policies and all harbour requirements and
- Manage implementation of compliance and law enforcement in the harbour.

In 2017, the South African government adopted its Comprehensive Maritime Transport Policy (CMTP) (www.transport.gov.za/documents/11623/44313/MaritimeTransportPolicyMay2017FINAL.pdf/4fc1b8b8-37d3-4ad0-8862-313a6637104c). This policy acknowledges existing the policies and legislation pertaining to commercial ports and aims to strengthen and review these going forward. In terms of small harbours, the policy identified several challenges to be dealt with in future, including:

- Cohesive legislative and regulatory framework on small harbours responsible for ensuring oversight, custodianship, management, operations, and regulations of the country's small harbours
- Small harbours public agency or authority suggested 'Small Harbours Development Authority' serves as a single point of accountability on the country's approximately fifty (50) small harbours (including public proclaimed, non-proclaimed and potential harbours, private harbours as well as landing sites).

Operation Phakisa (www.operationphakisa.gov.za/) is a government initiative established to unlock the ocean economic potential of South Africa, is seen to benefit from the implementation of this policy.

3.2.10 Tanzania

The Tanzania Ports Authority (TPA) was established by the Ports Act (No. 17 of 2004) as landlord port authority. TPA currently performs the role of both a landlord and port operator promoting the use, development and management of ports and their hinterlands (www.ports.go.tz/index.php/en/).

In 2017 an overarching Green Port Policy for Tanzania was prepared, in partnership with Deltares and HaskoningDHV (https://publications.deltares.nl/EP4006.pdf). This policy stipulates ways in which TPA can minimize/mitigate negative impact of climate change, reduce the environment risks in its operations and enhance climate change and environmental opportunities The policy includes an implementation enabling TPA to (global.royalhaskoningdhv.com/projects/green-port-policy-and-implementation-action-plan-for-tanzania-ports-authority):

- Move towards the attainment of ISO14001 accreditation in a pro-active, comprehensive and coordinated approach, addressing the impacts of port operations
- Make informed decisions on follow-up actions in strategic areas such as environmental management, energy efficiency, waste management, oil spill response, social impact and responsibility, stakeholder involvement and efficient port logistics and connectivity
- Base decision making on well-coordinated framework and vision on climate change and environmentally friendly port operations
- Create awareness among public and private stakeholders of the importance of being a Green Port.

The Zanzibar Ports Corporation (ZPC) is responsible for the management, operations, and development of ports on the Islands of Zanzibar (zpc.go.tz/about_us.html), The ZPC is a parastatal established under the Zanzibar Ports Corporation Act of 1997 (http://trade.tanzania.go.tz/media/act_1.pdf), operating under the Zanzibar Ministry responsible for Transport. The main objectives of the ZPC include:

- Promoting the development of the port sector for enhance socio-economic well-being of Zanzibar
- Insuring efficient operations in terms of economics, and safety and security.
- Promoting reasonable facilities for the handling and warehousing of cargo and goods
- Insuring efficient and effective financial administration in accordance with existing national laws and regulation.

The Zanzibar Maritime Authority (ZMA), established under the Zanzibar Maritime Authority Act (No. 3 of 2009), is another institution acting under the direct authority of the Zanzibar Ministry responsible for Transport (www.zma.go.tz/overview.php; Humphreys et al. 2019). Its main responsibility pertains to the regulation activities of shipping activities in sea waterways to ensure safety of navigation that are in line with the International Maritime Organisation's conventions, instruments, and codes. As part of their environmental responsibilities, they ensure the prevention of marine source pollution and protection of the marine environment, investigate maritime casualties such as loss of lives resulting from overloading on boats, in partnership with other public agencies and institutions.

4. ENVIRONMENTAL CONSIDERATIONS

Understanding the relationships between port activities and potential environmental problems and associated ecological and socio-economic consequences impacts provides relevant and valuable insight into type of tools and solutions to consider for inclusion in the Toolkit for Sustainable Port Development in a Blue Economy.

4.1 Concept of Ecosystem Services

Natural systems, such as coastal and marine ecosystems, provide society with a range of valuable ecosystem services contributing to their wellbeing. Ecosystem services are typically categorised (i) Provisioning services, (ii) Regulating services, Supporting services, and (iv) Cultural services (Millenium Ecosystem Assessment 2005). These services contribute to an array of human well-being factors such as security, basic material for good life, health, good social relations and freedom of choice and action.

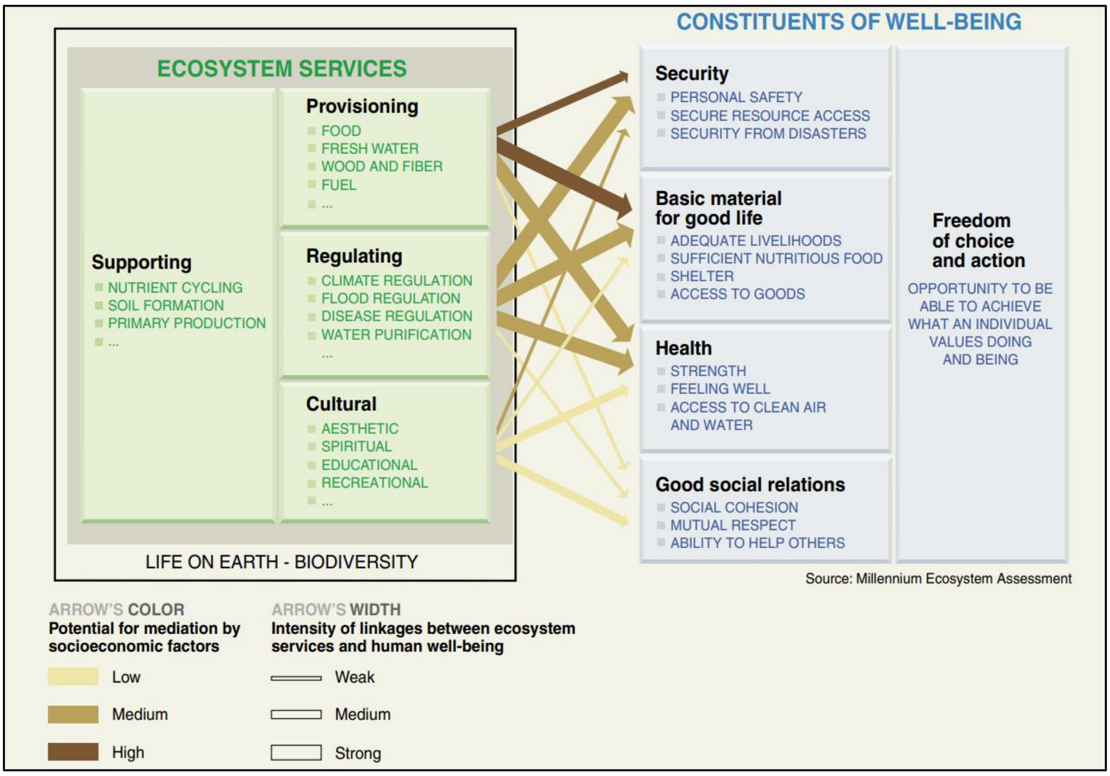

Figure 4.1 Key ecosystem services provided by natural ecosystems, such as coastal and marine systems, and links to societal well-being (Source: Millenium Ecosystem Assessment 2005)

Ports benefit from provisioning ecosystem services through their reliance on sheltered waters which some coastal systems, such as bays and estuaries, provide. As such sheltered environments also are favourable zones for sensitive natural habitats such as corals, seagrasses, and mangroves forests, which in turn are linked to various other societal services themselves. Conflict for space for port development and natural habitats and their ecosystem services therefore often arises. To minimise such potential conflicts it is important to create awareness of potential environmental problems associated with various port activities and practices so as to intervene or mitigate for potential impacts timeously.

4.2 Port Activities & Potential Environmental Problems

While ports are users of ecosystem services provided by sheltered coastal environments, numerous activities undertaken in ports contribute to an array of problems potentially causing negative impacts on other ecosystem services (Darbra et al. 2004; Darbra et al. 2005; ESPO 2020). Towards achieving sustainable port development such problems need to be identified and linked to the contributing activities to inform management and control interventions. For the purposes of this assessment environmental problems were broadly grouped into climate change, air pollution, water, sediment and soil pollution, physical problems including destruction of habitat or biota, harmful or invasive marine organisms and pathogens, underwater noise, and artificial light (Trozzi and Viccaro 2000; Jägerbrand et al. 2019; Moldanová et al. 2021). Table 4.1 provides a summary of major port activities, as well as their potential environmental problems, illustrating the complexity and interconnectivity.

Influence of adjacent urban and river catchments

Situated at the land-sea interface, environmental issues in ports may not be solely occur as a result of activities and inappropriate practices within ports. They can also be caused by activities and inappropriate practices in adjacent urban areas or upstream river catchments. For example, in many coastal cities stormwater runoff from municipal areas drain into the ports, contributing to pollution problems such marine littering and associated remediation and clean-up costs. Inappropriate agricultural activities in river catchments discharging into ports also contribute significantly to sedimentation, markedly increasing costs of maintenance dredging.

In such instances, management interventions do not reside with the port authorities but rather with the municipal or catchment management authorities. For this reason, it is critically important that port authorities establish formal port-city-catchment institutional structures through which to holistically coordinate environmental management interventions to achieve sustainability goals in their ports.

As regional monitoring data on environmental impacts associated with ports in WIO region were limited and not readily available (e.g., published in public domains), it was decided to derive such information from relevant international literature, primarily to create awareness of environmental issues associated with ports, and most importantly, to assist port developers and operators in linking different types of port activities to potential environmental problems so as to intervene or mitigate timeously.

Climate change-related problems mostly arise because of increased emissions of greenhouse gases, which in turn results in increased atmospheric temperatures, changes in rainfall (either increasing droughts or intensifying flooding), as well as sea level rise (SLR) and increases in the intensity of sea storms. While water wastage may not be directly linked to climate change it may well aggravate conditions in areas prone to increased droughts.

Port activities potentially contributing to air pollution, include (Trozzi and Viccaro 2000; Walker et al. 2018; Jägerbrand et al. 2019; Moldanová et al. 2021; Capelli et al. 2019; Široka et al. 2021):

- Vehicle and railway traffic (combustion products and volatile organic pollutants)
- On and offloading of cargo, specifically petroleum products generating volatile organic pollutants
- Ship and dry docks (producing volatile organic pollutants)
- Ship repair and demolition (e.g., heavy metals, volatile organic pollutants)
- Vessel emissions (greenhouse gases, particles, toxic organic pollutants)
- Emissions from industries and vessels, and cargo (e.g., fish processing plants livestock)
- Odours associated with inappropriate management of wastewater and solid waste.

Table 4.1: Port activities and potential environmentally related problems

ACTIVITY	PROBLEM																	
	Climate change		Air pollution			Water, sediment & soil pollution								Physical				
	Water wastage	Greenhouse gasses (increased temperatures)	Toxic chemical pollution	Dust (particle) pollution	Odours	Thermal pollution	High salinity	High suspended solids	Nutrient pollution	Toxic chemical pollution	Human pathogens	Hazardous solid waste	Solid waste (litter)	Harmful organism release	Habitat/biota destruction	Shoreline erosion	Under water noise	Artificial Light
CONSTRUCTION																		
Capital Dredging								●	●	●					●	●	●	
Earth works				●											●	●		
Night lights																		●
Energy consumption		●	●															
Construction vehicle traffic		●	●	●	●										●		●	
OPERATIONS																		
Water consumption	●																	
Energy consumption		●	●															
Maintenance dredging							●			●					●	●	●	
Vehicle and railway traffic		●	●	●	●					●							●	
Fire or explosion			●	●	●					●							●	
Night lights																		●
Waste disposal (general & hazardous)										●		●	●					
Urban stormwater runoff					●			●	●	●	●		●					
Catchment runoff (rivers)								●	●	●	●		●					
Dry docks and ship repairs - waste			●	●	●			●		●			●				●	
Industries – waste and wastewater					●			●	●	●	●	●	●	●				
Industries - atmospheric emissions		●	●		●													
Industries - Cooling water						●				●								
Industries - Desalination brine							●			●								
Open stockpiles - dust			●	●						●								
Storage facilities - spillage					●					●								
Vessels - solid waste (garbage, other)										●	●	●						
Vessels - spillage fuel/oil/cargo					●					●								
Vessels - emissions		●	●		●					●								
Vessels - wastewater		●			●			●	●	●	●			●				
Vessels – ballast water exchange														●				

Water, sediment and soil pollution primarily arises from waste and wastewater spills or discharges such as (Trozzi and Viccaro 2000; Walker et al. 2018; Jägerbrand et al. 2019; Moldanová et al. 2021):

- Oil and fuel spillage from vessels
- Accidental spillage of oils and chemicals during on and off-loading
- Washing and cleaning of tanks either in ports or on vessels
- Wastewater disposal from vessel and activities in port (e.g., industries, sewage, bilge water)
- Leaching from chemical from vessels (e.g., antifouling paints)
- Ballast water exchange (e.g., harmful, or invasive organisms)
- Solid waste disposal (including garbage and hazardous waste) from port activities and vessels.

Physical destruction of habitat and biota are primarily associated with activities such as (UNEP/GPA and WIOMSA 2004):

- Port construction (quays, rail lines, roads buildings etc.)
- Capital (associated with construction) and maintenance dredging.

Harmful and invasive organisms and pathogens mostly enter ports and surrounding coastal environments through ballast water when vessel exchange ballast water from one region into the water of another (Gollasch et al. 2015; Bailey 2015). Most primary and secondary invasions of aquatic invasive species via ballast water exchange occur in ports (Walker et al. 2018).

Noise problems in ports arise from activities such as (Trozzi and Viccaro 2000; Jägerbrand et al. 2019; Moldanová et al. 2021):

- Vehicle traffic (especially heavy vehicles)
- Cargo movement (e.g., quay cranes and pumps)
- Vessel propulsion mechanisms.

Artificial light in nearshore environments propagates easily and over long distances since aquatic landscape is open without barriers that hinder the spreading of light (Jägerbrand et al. 2019). Light sources above water surfaces allows light to penetrate the water, the extent depending on the light-transmittance qualities of the water and the character of the light source. In port, artificial light sources include:

- Night lights on vessels
- Night lights associated with port activities and facilities.

4.3 Environmental and Socio-economic Consequences

A vast array of ecological and socio-economic consequences can stem from environmental problems potentially associated with port activities, rippling into negative impacts on associated ecosystem services of affected coastal and marine environments (Table 4.2).

Climate change-related ecological consequences can include habitat loss, changes in species composition (linked to habitat loss and temperature increases), and subsequent chronic and acute effects on marine biota sensitive to such changes (Table 4.2). Socio-economic consequences pertain mostly to safety issues (human and property, associated with increased flooding and sea level rise) as well as potential water shortages. These consequences also can manifest in ports with potentially detrimental effects on people's safety and recovery costs. Major risks to disruption of port operations include coastal flooding and overtopping due to SLR, and heat stress impacts associated with higher temperatures (Hanson and Nicholls 2020; Izaguirre et al. 2021).

Air pollution problems can have chronic and even acute effects on marine biota where chemicals ultimately end up in adjacent coastal waters (Table 4.2). Such problems also have socio-economic consequences related to health risk to humans (Ballini and Bozzo 2015) that affects port workers and nearby communities, and contribute to loss in aesthetic value (e.g., dust) and other ecosystem services provided by ports such as tourism and recreational facilities. Odour problems manifest mainly in socio-economic implications (Capelli et al. 2019) greatly affecting aesthetic values in areas popular for real estate development, tourism, and recreational activities, also relevant to ports.

Water, sediment, and soil pollution mostly result in ecological consequences (UNEP et al., 2021). However, socio-economic consequences also occur, such as loss of aesthetic value (e.g., suspended solids, nutrient loading resulting in excessive algal growth, and solid waste) and human health impacts (e.g., toxic chemical, human pathogens, hazardous waste). Effects on seafood products and fisheries resources also can have socio-economic ripple effects, resulting in loss of product quality and revenue.

Table 4.2: Typical ecological and socio-economic consequences associated with port environmental problems

CONSEQUENCE	ENVIRONMENTALPROBLEM																	
	Climate change		Air pollution			Water, sediment & soil pollution								Physical				
	Water wastage	Greenhouse gasses (increased temperatures)	Toxic chemical pollution	Dust (particle) pollution	Odours	Thermal pollution	High salinity	High suspended solids	Nutrient pollution	Toxic chemical pollution	Human pathogens	Hazardous solid waste	Solid waste (litter)	Harmful organism release	Habitat/Biota destruction	Shoreline erosion	Underwater Noise	Artificial light
ENVIRONMENTAL																		
Physical loss of important habitat	●	●													●	●		
Smothering/entablement of marine life								●					●					
Disorientation of marine life (birds)																	●	●
Chronic/acute effects on marine life		●	●			●	●	●	●	●		●	●		●		●	●
Introduction of invasives														●				
SOCIO-ECONOMIC																		
Loss of aesthetic value				●	●			●	●				●		●			
Human health risk (contact or seafood)			●	●		●				●	●		●		●		●	
Human and property safety risk		●														●	●	
Loss of livelihoods (material & food)										●	●			●	●			
Commercial losses (tourism, fisheries)										●	●			●	●	●		

The introduction of invasive organisms can be a significant cause of changes in biodiversity (Bailey 2015; Gollasch et al. 2015). The introduction of harmful pathogens in ports, for example through ballast water, has found to pose serious risks to sensitive ecosystems such as coral reefs (Aguirre-Macedo et al. 2008). The ecological consequences of physical destruction of habitat and biota are well documented from many parts of the world, including the WIO region (UNEP/GPA and WIOMSA 2004). Such problems also have socio-economic implications pertaining to commercial losses in other coastal sectors, and loss of livelihoods.

While marine ecosystems can be naturally noisy because of, for example waves and marine mammals' vocals, human activities such as boating, resource extraction, fishing, and recreational activities have increased ocean ambient noise levels by about 15 dB over the past 5 decades (Pine et al. 2016). This is a problem as human induced noise differs from ambient underwater noise with respect to direction, frequency, and duration. Seabirds attracted to artificial light from ships or offshore platforms can become disoriented, collide with structures, starve, become dehydrated, or be taken by predators. Species that are nocturnal or light-sensitive also can be affected even if the exposure is to low light intensities and temporary (Jägerbrand et al. 2019).

5. HABITAT ASSESSMENT IN SELECTED PORTS

5.1 Approach

Port development incurs unavoidable environmental impacts, a primary one being associated with the obligatory need to develop large infrastructure which leads to physical alteration and destruction of coastal habitat. Along the WIO coast important habitats typically include *coastal forests, mangroves, seagrass beds and coral reefs*. It is critical that the location of these important coastal habitats is considered in early site selection phases of port development (both for new ports and expansion of existing ports). To adequately assess potential impacts of port development on coastal habitats the location and extent of these habitats needs to be known. These spatial data are best presented as geo-referenced maps, ideally using Geographic Information Systems (GIS). For engineering design purposes, and even for planning purposes, these data are required at high resolution, ideally sub-metre. These databases have typically not been available at early stages of port development, but with the application of modern remote sensing technologies they are increasingly becoming available.

As part of this study a detailed review on available spatial databases that potentially contain such data for the WIO was undertaken. A series of ports in the WIO region was selected for study, based on port type and representation across countries, as listed in Table 5.1.

Table 5.1: List of representative ports included as case studies for ecosystem impact assessment (possible option to make selection from and get variety)

COUNTRY	PORT	HARBOUR TYPE
Comoros	Moroni	Open roadstead (island)
Kenya	Mombasa	Coastal natural (mainland)
Madagascar	Mahajanga	Coastal natural (island)
Mauritius	Port Louis	Coastal breakwater (island)
Mozambique	Maputo	Coastal natural (mainland)
Reunion (France)	Réunion (new port)	Coastal breakwater (island)
Seychelles	Victoria	Open Roadstead (island)
Somalia	Mogadishu	Coastal breakwater (mainland)
South Africa	Durban	Coastal breakwater (mainland)
Tanzania	Dar es Salaam	Coastal natural (mainland)

Potential habitat datasets were identified as follows:

1. Adams JB, Veldkornet D and Tabot P. 2016. Distribution of macrophyte species and habitats in South African estuaries. S. Afr. J. Bot. 107: 5–11. https://doi.org/10.1016/j.sajb.2016.08.001
2. Adams JB, Fernandes M, Riddin T. 2019. Chapter 5: Estuarine Habitat Extent and Trend. In: Van Niekerk L, Adams JB, Lamberth SJ, MacKay F, Taljaard S, Turpie JK, Weerts S and Raimondo DC. (Eds.), South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm. CSIR report number CSIR/SPLA/EM/EXP/2019/0062/A. South African National Biodiversity Institute (SANBI), Pretoria, South Africa. Report Number: SANBI/NAT/NBA2018/2019/Vol3/A, pp. 52–75.
3. Allen Coral Atlas. 2020. Imagery, maps and monitoring of the world's tropical coral reefs. Data URL: https://doi.org/10.5281/zenodo.3833242 or https://allencoralatlas.org/.
4. Bunting P, Rosenqvist A, Lucas R, Rebelo L-M, Hilarides L, Thomas N, Hardy A, Itoh T, Shimada M and Finlayson CM. 2018. The Global Mangrove Watch – a New 2010 Global Baseline of Mangrove Extent. Remote Sensing 10 (10): 1669. https://doi.org/10.3390/rs1010669.
5. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J and Duke N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data (version 1.3, updated by UNEP-

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Information from these datasets was plotted at the selection of ports in the WIO and investigated for suitability in representing the extent and condition of the extent of estuarine and selected marine habitats. Overall, these datasets are derived from coarse-scale, freely available satellite imagery. They provide a powerful tool for global scale assessments of changes of these ecosystems. However, several omission and commission errors were apparent when viewing the data at the scale of individual ports. (Table 5.2).

Table 5.2: Availability and suitability of available geo-referenced data sets in selected ports in the WIO region (see listing of source databases above)

COUNTRY	PORT	CORAL REEFS	MANGROVE							SEAGRASS		
		3	1	2	4	5	8	9	10	3	6	7
Comoros	Port of Moroni	Y				Y	Y	Y		Y		
Kenya	Port of Mombasa	Y			Y	Y	Y	Y	Y	Y	Y	Y
Madagascar	Port of Mahajanga				Y	Y	Y	Y	Y		Y	Y
Mauritius	Port of Port Louis				Y	Y	Y	Y	Y		Y	Y
Mozambique	Port of Beira				Y	Y	Y	Y	Y			
Reunion (France)	Port Réunion										Y	Y
Seychelles	Port Victoria				Y	Y	Y	Y	Y		Y	Y
Somalia	Port of Berbera				Y	Y	Y	Y	Y		Y	Y
South Africa	Port of Durban		Y	Y	Y		Y	Y	Y			
Tanzania	Port of Dar es Salaam	Y			Y	Y	Y	Y	Y	Y		

Suitable	Partly suitable, with some spatial refinement	Not suitable, must be re-generated at port scales

There were some exceptions where available spatial data are partly suitable. For example in the case of South African estuarine habitat types have been manually mapped, and the data from this dataset shows considerably better representation than that available in the global datasets. This analysis indicated that finer-scale products will be required to detect changes in the narrow and very dynamic extent of these habitats for ports. Ideally these data will be sourced using drone or airborne images. The cost of this type of imagery could escalate data costs tremendously, especially because these areas are highly dynamic, and frequent temporal overpasses may be required to distinguish natural habitat changes from changes related to global change pressures (climatic and anthropogenic). Priority areas could be selected for the refinement of methods and outputs that can be compared to these global datasets. This will be useful for cost-benefit analysis and capabilities of remote sensing to contribute to a monitoring framework for the ports. Physical in-field mapping is quite likely going to be the most cost-effective method of establishing current habitat extents, but this cannot accurately inform past habitat extents. Moreover, the sensitivity and accuracy with which ecological condition and extent are assessed with in-field methods, lacks some of the advancements and benefits that certain remote sensing sensors can offer. The field is a rapidly evolving one and new tools, such as that offered by Google Earth Engine (GEE) provide considerable opportunity going forward.

To demonstrate this, and to make some assessment of temporal trends in habitat losses to port development in the last two decades, it was decided, as part of this study, to undertake a preliminary investigation in the application of GEE and available remote sensing imagery in the identifying habitat changes in and around ports at a resolution appropriate for at least the screening of change in habitats over time. In this case mangroves were chosen as a study habitat in selected ports in the WIO. As part of this situation assessment report, the Ports and Durban and Mombasa are used as case studies to demonstrate its application.

Mangrove cover was assessed using Landsat and Shuttle Radar Topography Mission (SRTM) datasets for the years 2000 and 2021. Various popular auxiliary indices datasets, namely the Normalized Difference Vegetation Index (NDVI), Enhanced vegetation index (EVI), Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI), Normalized Difference Water Index (NDWI), Normalized Difference Water Body Index (NDWBI), Normalized Difference Vegetation Index (NDVI), simple ratio RN (Red and NIR bands) and simple ratio SN (SWIR and NIR bands) calculated from the Landsat series were used to increase the accuracy of the mangroves classification. Topographic variables, such as elevation, are related to the mangrove distribution in the estuaries. Therefore, in this study, the 30 m elevations, slope, and aspect derived from the SRTM data were used as auxiliary variables for the classification.

Customized Google Earth Editor Code scripts were used to analyse the selected images. The median value of each pixel in the respective years was used to smoothen the seasonal effect in generating the yearly images. Each of the scripts used comprised of five main steps, which include: Acquisition of satellite datasets from the image collection (Landsat), selection of study area boundary, selection of training and testing data, image classification, validation and accuracy assessment, and the statistical area calculation and exporting of the results. SRTM dataset was used to mask out the high elevation areas, and spectral indices such as Normalized Difference Mangrove Index-NDMI; Modified Normalized Difference Water Index-MNDWI; Green Chlorophyll Vegetation Index- GCVI; Normalized Difference Vegetation Index-NDVI values derived from remote sensing datasets were used to improve the mangroves cover outputs. Random Training samples were obtained from high resolution Google Earth imagery through GEE. Seventy percent (70%) of samples were used to train the RF classifier, whereas 30% were used to assess the accuracy of the developed land cover maps. A pixel-based supervised classification Random Forest (RF) machine learning-based algorithm in GEE was used to classify the images to “Mangroves” and “No mangroves” land cover types. The RF algorithm has gained popularity over the last two decades because of good performance with high dimensional and multi-source datasets, virtuous handling of the outliers and noisier datasets, higher accuracy compared with other popular classifiers and high processing speed. The outputs of the analysis were complemented with the Global Mangrove Watch dataset.

5.2 Temporal Change in Habitat of Case Study Ports

This section reports on the findings of two case studies on temporal changes in habitat over the last ~ two decades, the Ports of Durban (South Africa) and Mombasa (Kenya). Based on the lack of suitable spatial data, these two ports are used as case studies to demonstrate how the above tools can be implemented to assess temporal changes in natural habitats in port environments, in this instance focusing on mangroves.

5.2.1 Port of Durban

Durban Bay (Port Natal) as a tidal estuarine bay, in the lee of a high vegetated bluff was identified as a potential natural shelter to seagoing vessels by early Portuguese exploratory voyages in the 15th century. The first record of a ship to sail over the sandbar and moor in the Bay was the Noord, in 1689. Its development as a port, however, only really began after being surveyed by James Saunders King in 1823 and the establishment in the following year of Durban as a trading post. The port's location was motivated more by the fact that it was the only site for hundreds of kilometres on an otherwise treacherous coast where seagoing vessels might land, rather than it being a natural harbour. The shallow nature of the sandbar at the mouth made access to the sheltered lagoon waters dangerous and was a constraint to the port's growth for many years. This became even more significant as deep draught steam powered vessels replace the old windjammer fleets. It was only with the availability of modern dredging equipment (and particularly suction dredging) that the "battle of the bar" was finally won and in the early 1900's significant deepening of the entrance was achieved to allow entry by the first mail ships. This facilitated major new port expansion, which both stimulated, and was further simulated by landside development in rail and road infrastructure, and city, agricultural and industrial area.

These developments, cumulatively, have had massive impact on natural habitats in the original estuarine system. Prior to port and city development, Durban Bay was characterised by extensive mangrove swamps, intertidal and shallow subtidal sandflats, mudflats, and seagrass beds surrounded by tidal and freshwater swamps. The Bay has subsequently undergone extensive physical and bathymetric modifications. These include a widening and deepening of the mouth to form the entrance channel, deepening of much of the water body for vessel navigation, hardening of much of the perimeter to form quay walls, removal of mangroves and infilling of intertidal and shallow subtidal sand- and mudflats for port and city infrastructure. Habitat losses at the end of the 20th century (excluding surrounding freshwater swamps) were estimated at 57% of the Bay area, 86% of tidal flats, 97% of mangroves and 96% of natural shoreline (Allan et al. 1999, see Figure 5.1).

The full impact of these habitat losses on the system's biota cannot be quantified. No records of ecological surveys of the original Durban Bay exist. The earliest recorded surveys are from the early 1950's (Day and Morgans 1954) after the Bay had already undergone extensive modification due to port and city development. These surveys indicated that the system at that time, despite being in a modified state, was still remarkably productive and supported a diverse flora and fauna.

The subsequent 25 - 30 years, however, saw a marked degradation in the Bay's ecological state. The major causes for the ecological deterioration that occurred between ~1950 and ~1980 were identified as Begg (1978, 1984):

- Loss of vegetation (this included primarily mangroves and *Zostera* seagrass)
- Alteration and destruction of natural substrates habitat as feeding grounds (referring to dredging impacts on sand and mud substrates, and loss of these shallow water habitats)
- Industrial pollution
- Increased tidal exchange.

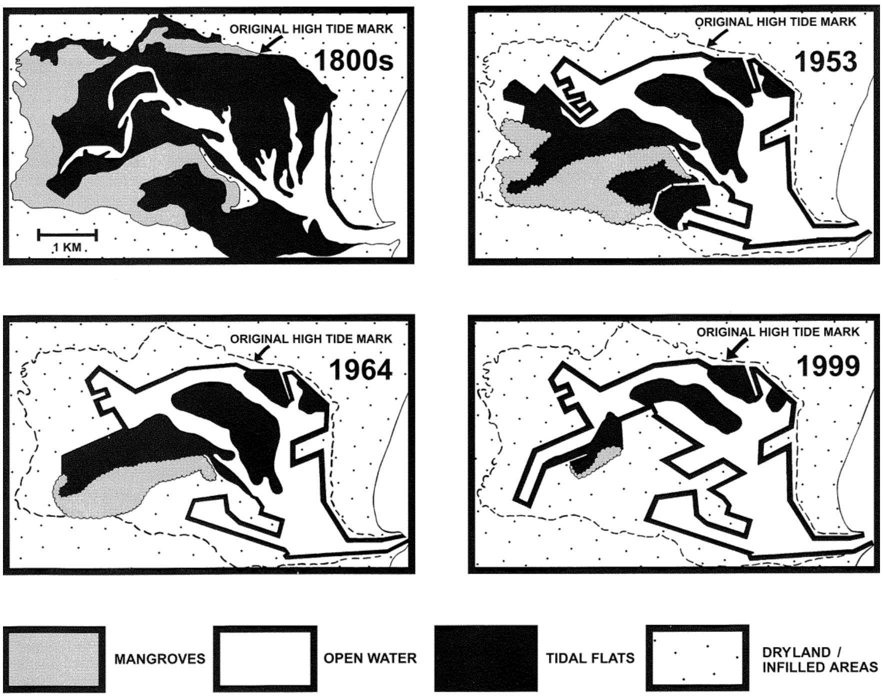

Figure 5.1 Habitat losses in Durban Bay (from Allan et al. 1999)

In the 45 years, subsequent to Begg's (1978) synopsis on the state of Durban Bay, further degradation and loss of habitat and of ecosystem function has occurred. This has involved a reduction in species diversity caused by losses of sensitive species and/or reductions in their abundance. This is best documented in the analysis of the Bay's avifauna by Allan et al. (1999) but is reflected in all biotic assembles. Monitoring, research consultancy reports and published scientific papers over the last 25 years are consistent in their opinion that the ecological health of the Bay is in a state of decline.

The impact of loss of structural habitat (sandbanks and mudflats, mangroves and *Zostera*) was, in all likelihood, the predominant vector of ecosystem degradation between ~1950 and ~1980. Major port developments occurred during this period. Pollution undoubtedly played some role, with domestic and industrial effluent disposed of from an outlet on North Pier at the port entrance until 1969. Potential impacts of this practise were mitigated by restricting disposal to outflowing tides and major pollution events were likely the result of spillages rather than persistent contaminant loading. However concomitant with urban development around the Bay and in its catchments, river and stormwater contamination became increasingly problematic to the point that Begg (1978, p. 247) described the Bay as functioning as a "giant stormwater sump for the city of Durban". Monitoring programmes conducted in the last decade all indicate degraded water and sediment quality in the Bay, most notably in the vicinity of river and stormwater inflows from the surrounding city.

Past port and city development has, therefore, already affected the significant majority of the original area of Durban Bay, through physical alteration and destruction of habitat. The rate of port expansion has decreased in recent years, largely constrained by the decreasing amount of space left to develop. Future port growth now relies on the expansion of quays and wharfs at the expense of open water and the little natural intertidal and subtidal habitat that remains. The surrounding urban population and city development, on the other hand, has continued to increase, with concomitant increases in pollutant loads to the port via river and stormwater inflows. This increasing pollution loading into a decreasing water area with reduced assimilative capacity through loss of natural habitat has reduced the ecological resilience of the Bay. Pollution impacts, such as fish kills experienced in recent years are the result.

Durban Bay's remaining ecological value as a functional estuary is dependent on the remaining natural habitats and water quality that sustains aquatic life. Remaining natural habitats in the system are limited to mangroves, sand- and mudbanks (Figure 5.2)

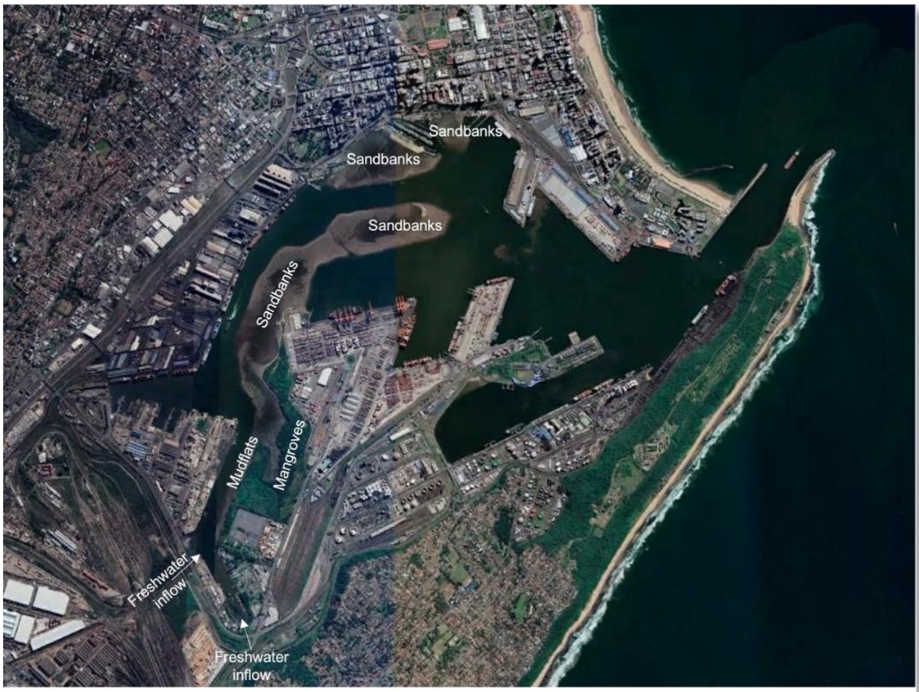

Figure 5.2 Remaining natural habitat losses in the Port of Durban Bay (imagery from Google Earth)

Even this small fraction of natural habitat that remains in under threat of ongoing development and poor water quality. To investigate changes in the mangrove habitats in the Port of Durban over the last two decades (since 2000) remote sensing techniques and GEE were applied to available Landsat imagery. The results indicate that mangrove habitat has increased in recent years, an outcome that might seem surprising. Indeed, mangroves appear to have increased in extent by over 30% since 2020 (Figure 5.3).

This confirms the observations of a report author (SW) who has first-hand experience of the system over the last three decades. Mangroves have steadily, over the years, extended their boundaries from existing stands and recruited to, and established on new areas of previously unvegetated sand- and mudbank in the port. The extent data from remote sensing admittedly do not necessarily indicate improved mangrove health, and indeed, there are areas of mangrove die-off in the Port of Durban. These are the result of impacts of recent oil spills in the city catchment rather than port or shipping activities. The mangrove extent data also do not point to the fact that sandbank habitat in the Port of Durban remains under threat from development. In this case the threat does arise from proposed ongoing port development, and the need to deep and widen shipping canals and basins. Indeed, these open unvegetated habitats are more threatened in the port than mangroves. This is also true of the wider subtropical bioregion of South Africa. Here estuarine sandbanks have suffered greater losses than mangroves in the last 50 years. These habitats are often overlooked because the lack vegetated structure and are regarded as open (and by implication empty) area. This is far from the truth. Sandbanks and mudflats are also critically important habitats for some invertebrate, bird and fish species.

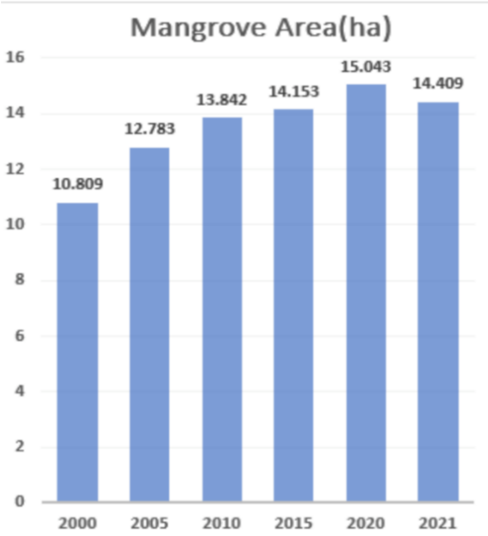

Figure 5.3 Estimated change in mangrove area in the Port of Durban (2000 to 2021)

Nevertheless, these data indicating growth of mangrove habitat within the Port of Durban do indicate the propensity for natural systems to adapt to disturbance, and if given space and adequate conditions (water quality), the ability to recover, or regenerate to establish new equilibria. This is even better demonstrated in the Port of Richards Bay some 200 km to the north. This natural resilience presents opportunity for ecological design principles to be successfully applied in port development, and for restoration and rehabilitation to be successfully undertaken to mitigate impacts of historically poor design and development choices. This highlights the potential for sustainable port initiatives.

5.2.2 Port of Mombasa

As in the case of Durban, the Port of Mombasa has a long history, dating back to the 16th century, when it was visited by Portuguese explorer Vasco da Gama. It was first a trading port for the Portuguese, and later, in the 18th century, developed under the British East India Company as a major trading hub. This included the construction of a new dockyard and the introduction of steam-powered vessels. In the 19th century, the port was further developed with the construction of new warehouses and a maritime college. In the early 20th century the port underwent further modernization with the construction of a new port and the introduction of modern cargo handling facilities. Since the 1950s, the Port of Mombasa has gone through several development phases. In the 1970s, the port was expanded and modernized with the introduction of new container handling facilities and a new container terminal. In the 1990s, the port was further developed with the construction of a new passenger terminal and the introduction of new oil tanker facilities. More recently (since 2000) substantial new development has occurred enable the port to handle larger vessels and increase its cargo capacity.

The construction and expansion of the Port of Mombasa has had clear impacts on natural habitats in the original natural estuarine embayment as well as the nearshore marine system at the bays entrance. The first major environmental impact of harbour development in Mombasa was the loss of mangrove forests. The construction of the port required extensive land reclamation which resulted in the destruction of several hectares of mangrove forests. The expansion of the port in the 1950s and 1960s, with the construction of new wharves and container terminals, involved extensive dredging which resulted in the loss of several hectares of seagrass beds and coral reefs. A detailed assessment on the effect of development on natural ecosystems in the Port of Mombasa was recently undertaken (UNEP et al. 2021). Key findings of this study include:

- Port activities such as dredging, channel widening, and terminal construction have likely increased chlorophyll and Wavelength of Light/Photosynthetically Available Radiation (KDPAR) over the 20-year period from 2000 and 2021
- Land use change in and around the port, has been exclusively driven by human factors, with built up areas and agricultural areas increasing at the expense of sparse forests, forests and bare soils
- Ecosystems at the intersection of human land use and marine environments have also suffered as mangrove cover has decreased and water body surface area has increased over this period.

The loss of natural habitats in Mombasa has had significant environmental impacts. The destruction of mangrove forests has led to increased coastal erosion and a reduction in the capacity of the shoreline to absorb storm surges. The loss of seagrass beds and coral reefs has had a negative impact on the local fishing industry, as fishery species rely on these habitats for food and shelter.

According to the Global Mangrove Watch data mangrove coverage around the Port of Mombasa in 2020 was 2870.77 ha. Seagrass coverage, as obtained from RCMRD, was estimated at 1166.81 ha, while the Allan atlas (2020 - https://allencoralatlas.org/) estimated coral reef coverage at about 1386.81 ha (Figure 5.4).

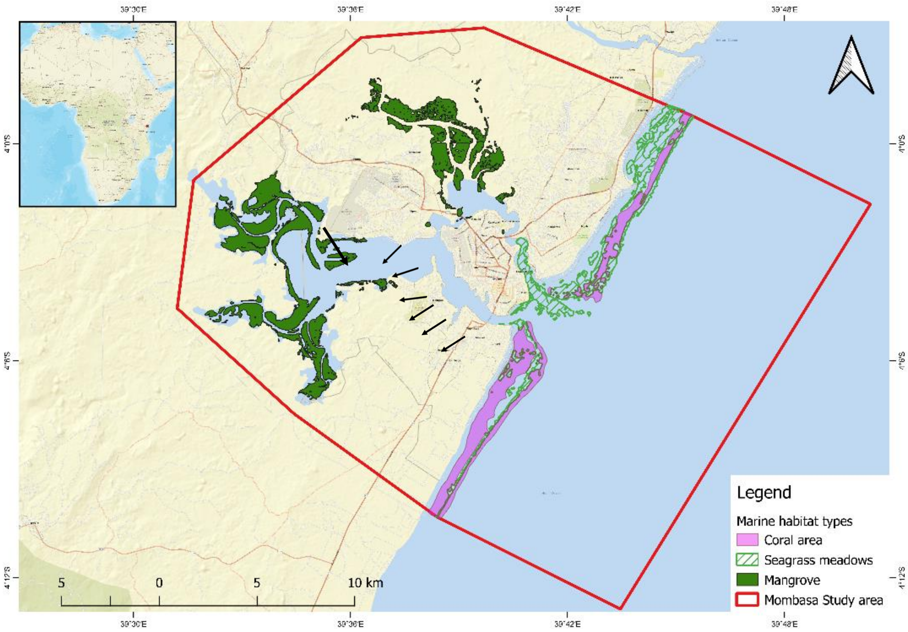

Figure 5.4 Distribution of key coastal habitats in and around Port of Mombasa (black arrows indicate main area of historical and present port development)

The Landsat classification and application of GEE to quantify temporal change in mangroves cover from 2000 to 2021 for the current study indicated an overall gain of 69.84 ha of mangroves (2741.76 ha in 2000 to 2811.6 ha in 2021. Habitat gains and losses are mapped in Figure 5.5. Specifically evident is the development of more mangrove cover on shallow banks to the left of the Port of Mombasa. Dredging for port expansion around 2011 may have contributes to this mangrove proliferation. The major infrastructural development that occurred as part of this port expansion was the construction of the Second Container terminal in the area demarcated Figure 5.5. This has clearly not contributed to direct losses of mangrove habitat in the port but has almost certainly rather resulted in loss of intertidal and shallow tidal sand- and mud flats. As in the case of the Port of Durban therefore, mangrove coverage in the immediate vicinity of the port has increased in recent decades, but port development continues to occur at the expense of other natural habitat types.

In recent years, the Kenyan government has recognized the need to mitigate the environmental impacts of harbour development in Mombasa. The government has introduced measures to protect and restore natural habitats, including the restoration of mangrove forests and the creation of a marine protected area around the harbour. However, the ongoing expansion of the port, including the construction of a new railway line and container terminal, continues to pose significant environmental challenges that must be addressed in a responsible and sustainable manner.

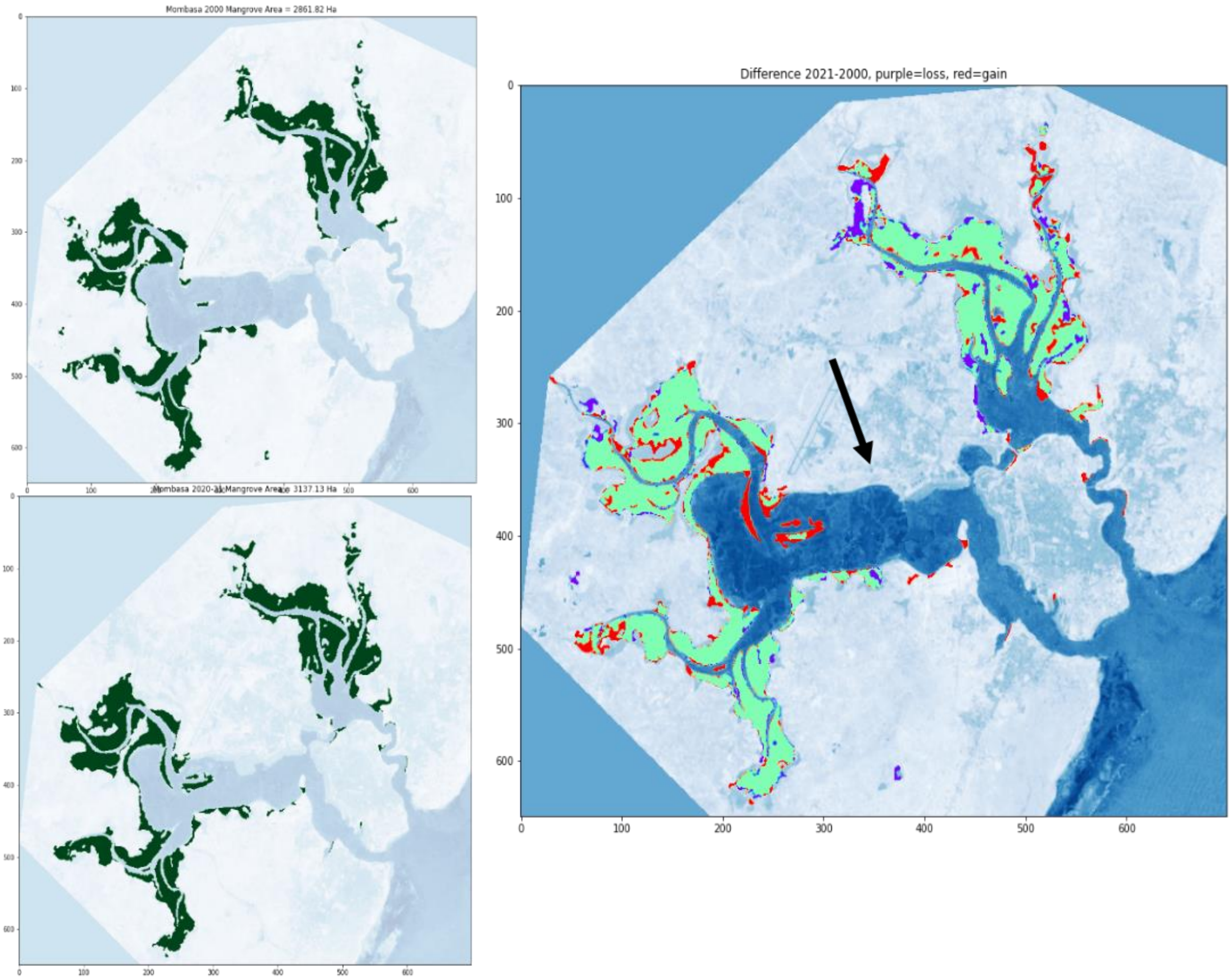

Figure 5.5 Estimated change in mangrove cover between 2000 (top left) and 2021 (bottom left) in the Port of Mombasa and surrounds. Losses and gains (purple = loss; red = gain) shown (right) (black arrow marks location of recent major port development, Second Container terminal)

5.3 Future Considerations for Geospatial Data Generation

Based on the findings of this study, resolution of currently available global and regional geospatial databases for coastal habitats (e.g., mangroves, coral reefs, and seagrasses) is not at suitably fine scales to be used at port planning and design stages.

Preliminary studies investigating the ability of remote sensing technologies such as Google Earth Engine (GEE) to provide geospatial information at local scales were tested in Ports Mombasa and Durban. Results showed promise for above ground habitats, such as mangroves able to track change in coverage over time.

The limitations of this technology are the lack of historical images, e.g., prior to port development in these areas, to quantify longer term changes in habitat because of ports construction. Also, based on experience in local port planning and design studies, resolution of spatial data should at least be 5 x 5 m for strategic planning, and ideally at sub-meter resolution for detailed design and monitoring purposes.

More sophisticated remote sensing technologies are fast developing and should be further investigated, to include other important coastal habitats such as coral reefs, seagrasses, and sandy habitats (e.g., sand banks). The use of remote sensing technologies in generation other environmental data types, such as water quality change (e.g., using water colour) also needs to be further explored.

While the focus of geospatial data for use in port planning and management is typically for the spatial demarcation of the port space, it is important to extend geographical boundaries of geospatial data layers to adjacent near-shore systems which influence, and are influenced by, ports and port activities. Examples are anchorage areas and adjacent shorelines that may be influenced by pollution or changes in sediment dynamics because of port structure and operations. Numerical modelling techniques to simulate oceanographic circulation and pollutant transport processes are useful tools that can be used to determine such geographical boundaries.

It is recommended that future development in the generation of high resolution ecological geospatial data be coordinated across countries in the region. Ideally, standard methods for the generation of such data should be developed and agreed upon. Doing so will enable the region to conduct comparative studies both spatially (across countries) and temporally (over time in specific ports). This could be achieved through the establishment of a Regional Network or a Community of Practice comprising both data scientists and ecologists (key to assist in ground truthing and interpretation of geospatial data).

An underpinning requirement to successful implement such data technologies is commitment from port authorities, in collaboration with other regional and national networks with interests in collating and applying high resolution ecological data, to invest in such endeavours. Investment should be pre-emptive, early enough in the port development cycle to ensure that negotiations pertaining to coastal habitat protection and/or trade-offs are incorporated in port (spatial) planning from the site selection stage. These data will also be valuable later, in the operational stages, to inform port environmental monitoring programmes.

6. CONCEPT OF SUSTAINABLE PORTS

6.1 Rationale

Sustainable ports refer to ports which adhere to the concept of resource saving and environment-friendly development, actively fulfilling its social responsibilities, and comprehensively adopting technologies and management measures that are conducive to saving resources and energy, protecting environment and ecology, and coping with climate change – Guo and Liu (2018)

Although rooted in ancient human history, sustainable development emerged as a paradigm in the early 1900s in response to failures in conventional development focussed only on achieving growth in gross domestic product (Pintér et al., 2012; Villeneuve et al., 2017). An inability to distribute wealth fairly and detrimental impacts on the natural environment and society are key failures of the conventional economic development model, which might be addressed by sustainable development principles that consider environmental, social, and economic issues in the light of cultural, historic, and institutional perspectives (Waas et al. 2011).

Sea ports, by their very nature, are complex environmental systems given the magnitude of potential impacts associated with their activities, including atmospheric emissions, dredging, wastewater discharge, and solid waste. Environmental impacts can occur due to normal port activities or by accident (Darbra et al. 2004; Darbra et al. 2005). In their simplest forms, 1st generation ports operated in areas of uncontested spaces, benefiting from seascapes in which they could be situated safely and cost-effectively without competition (Kaliszewski 2018; Lee et al. 2018). However, society has evolved, with rapid coastal urbanisation, growing global trade, stakeholder emancipation and depletion of natural resources (e.g., through physical alteration and destruction of habitat, pollution, and unsustainable levels of exploitation). As a result, port systems can no longer operate without acknowledging and incorporating societal and environmental considerations in their planning and management (e.g., 5th generation ports). The port industry therefore faces increasing challenges in addressing societal and environmental considerations while at the same time having to provide adequate capacity and cost-effective services for trade (Lam and Van der Voorde 2012; Roh et al. 2016).

In 2015 the United Nations adopted the 2030 Agenda for Sustainable Development with 17 Sustainable Development Goals (SDGs) (UN 2015). With the adoption and establishment of the concept, monitoring and assessment of progress in achieving Sustainable Development have become necessary, and the concept of sustainability assessment has emerged (Sala et al. 2015). The World Ports Sustainability Program (WPSP), launched in 2018, aims to contribute to the sustainable development of world ports aligned with the UN's Sustainability Agenda and SDGs. The programme is led by the International Association of Ports and Harbours (IAPH) in partnerships major port industry-related organizations (WPSP 2020).

These challenges and the call for sustainable development stimulated the development of concepts such as 'Green Ports' with the primary objective of balancing environmental challenges and economic demand (Bergqvist and Monios 2019; Lam and Notteboom 2014) and striving for sustainability through increasing both economic and environmental competitiveness (Maritz et al. 2014). While some claim that sustainable port management must include the broader topic of ecosystem protection (Schipper et al. 2017), others argue that green ports implicitly will lead to positive outcomes on their economic performance (Lam and Van de Voorde 2012). Nevertheless, with increasing public and regulatory pressures, port authorities around the world are compelled to pursue sustainable port development to safeguard their 'license to operate' and to grow their economic and environmental competitiveness (Lam and Van der Voorde 2012; Roh et al. 2016; Darbra et al. 2004). The concept of 'Sustainable Ports' builds on 'Green Ports' by considering social sustainability, in essence advocating the need for port development to create a balance between economic growth, environmental protection and social progress to secure its long-term future (Hiranandani 2014; Taljaard et al. 2021).

Climate change and its contribution to sea-level rise and increased storminess (e.g., Azarkamand et al. 2020) is another major threat to port sustainability into the future to which ports can respond in two ways (HR Wallingford and British Port Association 2021):

- Adaptation - upgrading existing infrastructure and designing new infrastructure to withstand the main impacts of climate change, such as sea level rise and flooding where appropriate measures will depend on the extent and timing of future change and its impacts
- Mitigation - reducing greenhouse gas emissions to contribute to reducing future climate change.

Several initiatives in the WIO region have already started to adopt sustainable development initiatives, such as (see UNEP et al. 2023b):

- Kenya Ports Authority (KPA) has adopted a Green Port Policy (GPP) that is intended to address the negative impacts of port operations and is geared towards integration of environmental sustainability in port development/operations and significant reduction in greenhouse gas emissions. The policy focuses on initiatives on climate change mitigation/adaptation, use of renewable energy and recognizes the importance of stakeholders and partners towards achieving its sustainability objectives. Currently, the focus of the GPP is on the Port of Mombasa, but the KPA plans to expand its scope to include other ports managed by them, including the Ports of Lamu and Kisumu, and the dry ports.
- The Port of Maputo is implementing initiatives to reduce the emission of greenhouse gases. Currently tugs and pilot boats turn off their generators when moored and electricity is supplied by sources installed on the pier. The Maputo Port Development Company (MPDC) is also undertaking restoration of forests and tree planting.
- The government of Tanzania, through the Tanzania Ports Authority (TPA), has been taking steps to improve port sustainability to protect the marine environment. In consultation with Royal HaskoningDHV and Deltares a Green Port Policy (2018) has been developed specifically aimed at greening both existing operations as well as the design, implementation, and operations of new infrastructures in the Port of Dar es Salaam.
- Madagascar's largest and main seaport, the Port of Toamasina, has been increasing its container reception and storage capacity, whilst still committed to environmental protection as per national law and adopting good examples from other countries 'going green'.
- In South Africa, sustainability and sourcing new and alternative energy sources has been one of Transnet National Ports Authority's (TNPA) goals in recent years. To this end the TNPA is embarking on the installation of solar technologies to alleviate the country's power challenges and to support greener operations in its ports. One such successful initiative is the greening of energy sources at lighthouses and other marine aids to assist with navigation of vessels within port limits and along the coast.
- The Seychelles Port Authority (SPA) has been engaging in several green port initiatives involving the development of a National Heritage Plan for Port Victoria, and an Environmental and Social Policy to be followed by the development of an Environmental Management System towards achieving ISO 14001 certification.
- Port Management Association East and Southern Africa (PMAESA) together with the Maritime Technology Cooperation Centre-Africa (MTCC-Africa) is in consultation to sign a memorandum of understanding on baseline energy audit surveys and establishing the extent to which ports in the region have embraced GPP.

Traditional vs Sustainable Ports

Table 6.1 summarises a hypothetical scenario depicting 'traditional' or 'business as usual' port practices undertaken in the region, versus alternative 'sustainable port' practices that could be implemented towards sustainable future development. These are organised into four main components, namely port planning and design, port construction, port activities and industries (operations) and vessels in ports (operations) (Ares Moreno 2018).

Table 6.1: Key differences between traditional ports and sustainable ports (Source: Ares Moreno 2018)

ASPECT	BUSINESS AS USUAL	SUSTAINABLE PORT
Stakeholders	No meaningful participation of stakeholders or community and normally only during ESIA	Co-creation with communities and stakeholders to generate an added value
Economic driver	Benefits/Economy	Green growth/ Economy, social and environment
Relation with nature	Replacing nature	With nature/develop nature along with port
Mentality	Short term (current benefits)	Long-term (future benefits)
Technology	No use of new and innovative technological developments	Involvement of technological and societal developments to enhance transition towards green growth
Port Authority role	Re-active landlord	Pro-active landlord in development of region and logistic chain
Energy	Energy obtained from fossil fuels	Energy efficiency from renewable sources
Resources	'Take, make and dispose'	Reuse of resources
Air quality	No special measures for reducing air pollution during operation	Improving environmental performance through programmes to reduce emissions to a minimum during operation
Biodiversity	Reduction of negative impact on biodiversity	Enhancement of biodiversity and conservation areas
Cargo	Allowance of any type and origin of cargo	Attract diverse cargo, turnover from non-fossil cargo
Vision of sustainability	Sustainability as a legal obligation	Sustainability as an economic driver
Site location selection	As per land ownership and/or without preliminary studies	As per optimization of material, in harmony with nature, minimum negative biodiversity impact & minimum negative community impacts (e.g., SEA process)
Growth approach	Focuses on Gross Domestic Product (GDP) growth	Elimination of sources of inefficiency, promotion of innovation, reboot of new economic opportunities from emergence of new green markets and activities
Environmental impacts	Compensation of impacts	Avoidance of impacts
Sustainable actions extent	Following actual regulations, ESIA	Long-term vision, irrespective of actual regulations
Use of material	No re-use/optimization of material	Use of material efficiently, including naturally present materials and land resources for functional requirements and for added value
Dealing with future uncertainty	Scenario-based planning for making quantitative forecasts	Adaptive planning, including flexibility in planning and design as a means towards sustainability
Design decisions	Based on the project boundaries	Based on understanding whole system
End of life cycle	Subject is left to future generations	Subject is treated from planning phase, reducing restrictions for future urban redevelopment

These aspects may relate to various stages of port planning and development as illustrated in Table 5.6.

Table 6.2: Relevance of key aspects across port development phases (Source: Ares Moreno 2018)

ASPECT	PORT DEVELOPMENT PHASE				
	General	Planning	Design	Construction	Operations
Stakeholders		●	●	●	●
Economic driver	●				
Relation with nature			●		
Mentality	●				
Technology				●	●
Port Authority role	●				
Energy					●
Resources				●	●
Air quality					●
Biodiversity		●	●		
Cargo					●
Vision of sustainability	●				
Site location selection		●			

ASPECT	PORT DEVELOPMENT PHASE				
	General	Planning	Design	Construction	Operations
Growth approach	●				
Environmental impacts		●	●		
Sustainable actions extent	●				
Use of material		●	●	●	
Dealing with future uncertainty	●				
Design decisions			●		
End of life cycle		●	●		

6.2 Alignment with Key Environmental Processes

To contextualise environmental assessment processes pertinent to ports, it is useful to align them with the six sequential stages in the port planning and development cycle. These are site selection, master planning, design, construction, operations, and monitoring, and they can be viewed in a cyclical, logical ordered process. For sustainable port development to occur successfully in practice, environmental processes must be integrated into organisational decision-making processes as part of the traditional port development cycle. Towards achieving this, Taljaard et al. (2021) proposed a framework for Integrated Port Management (IPM) that conceptualises alignment of various environmental assessment processes with the port development phases (Figure 6.1). This recognizes the different time frames in the port development cycle, where the larger cycle, involving site selection, planning, design and construction of new or expansive port infrastructure, represents stages typically occurring at 5-year (or longer) intervals (i.e. longer time scales). The smaller cycle (operations and maintenance and monitoring and auditing) nested within the larger cycle, represents stages that occur continuously, on much shorter (i.e. day-to-day) time scales (Taljaard et al. 2021).

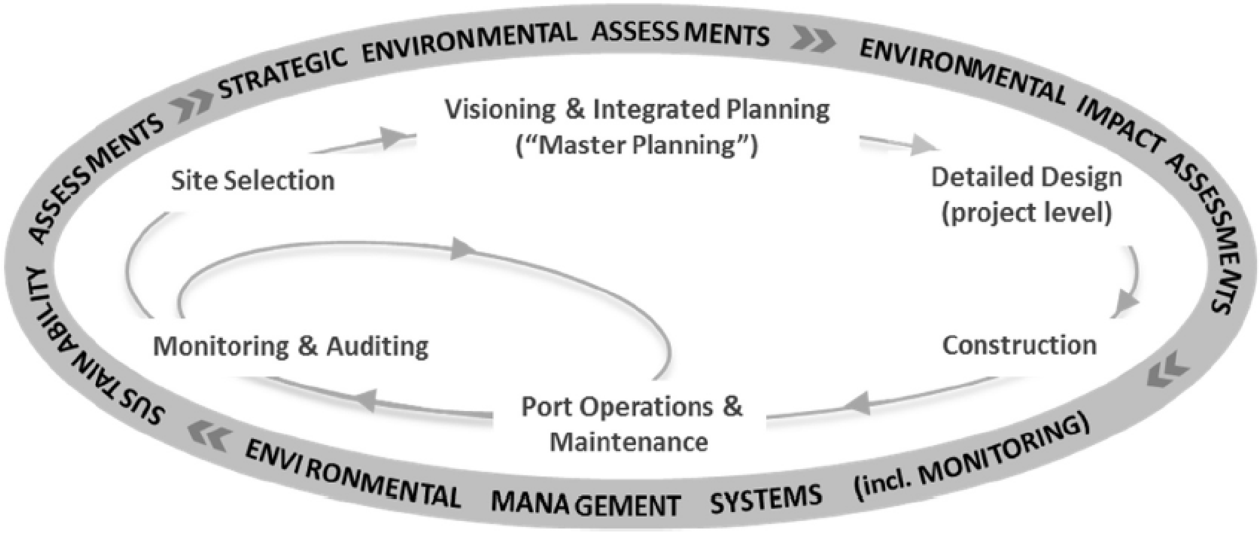

Figure 6.1 Generic port development cycle (inner circles) embedded in the Framework for Integrated Port Management (IPM), conceptualising alignment of environmental assessment processes with port development phases (Source: Taljaard et al. 2021)

Towards achieving more sustainable ports, key environmental processes are increasingly becoming part of port development processes. Internationally environmental processes such as strategic environmental assessment (SEA) (e.g., Dublin Port Company 2012a, 2012b), environmental and social impact assessment (ESIA), and environmental management systems (EMSs) (e.g., Gupta et al. 2005; Darbra et al., 2004; Darbra et al., 2005; Hussain 2018; Lawer et al. 2019) are being implemented in port development. Globally, sustainability assessments also are finding their way into port management (e.g., Lu et al. 2016; Pope and Grace 2006; Schipper et al. 2017), embracing inclusion of the SDGs of Agenda (2030) (e.g., Nitsenko et al. 2017).

6.2.1 Strategic Environmental Assessment

Strategic Environmental Assessment (SEA) evolved to determine the environmental implications of policies, plans and programmes. There are numerous definitions reflecting different understandings of its purpose (RSA DEAT 2004). Two of the most popular interpretations are:

- 'ESIA-based' SEA, primarily focusing on determining the environmental implications of a proposed policy, plan or programme (e.g., Partidario 1999)
- 'Sustainability-led' SEA, primarily focusing on its role in facilitating the move to sustainability by enabling the proactive consideration of the objectives of sustainability at the earliest stages of decision-making and facilitating the development of a sustainability framework to guide the development of new plans and programmes and/or to assess existing plans and programmes (e.g., Therivel et al. 1992; RSA DEAT 2004).

SEA constitutes a powerful tool for sustainable development that can strengthen decision-making processes (Arce and Gullon 2000). However, the role of SEA is determined by its place in the decision-making process. For example, SEA can be used to assess a proposed policy, plan or programme that has already been developed, or it can be used to develop, evaluate, and modify a policy, plan or programme during its formulation. Alternatively, SEA can be used to raise the profile of the environment, or it can have an integrative role, where the focus is on combining environmental, social, and economic considerations (Kørnøv and Thissen 2000; DEAT 2004).

Although SEAs generally may not yet be a legislated requirement for port development in the WIO region, it value in proactively addressing environmental and social contexts widely recognised. Benefits include (e.g., Therivel et al. 1992; Therivel and Partidario 1996; Fischer 2002 in DEAT 2004; Ports Australia 2013):

- Reducing consequential, project-specific assessment timeframes
- Addressing the causes of environmental impacts rather than only treating the symptoms of environmental deterioration
- Assisting the integration of the concept of sustainability into strategic decision-making, e.g., through determining of limits of acceptable change and the identification of sustainability targets and indicators, ensuring that development is within sustainable limits
- Providing the context for lower levels of planning and decision-making
- Providing for systematic consideration of the environment and socio-economic conditions at policy, plan, and programme levels of decision-making
- Increasing clarity regarding 'whole-of-port' monitoring and adaptive management requirements
- Increasing clarity for government agencies – including for example, city planning and infrastructure, environment and heritage and transport/freight agencies
- Facilitating increased public acceptance and transparency of the policy through stakeholder because SEA is inherently based on the participation of the public, non-governmental organisations, and other institutions from very early on
- Strengthening and streamlining subsequent ESIA processes having assessed a broader range of alternatives, considered cumulative effects, and facilitated the maintenance and enhancement of a chosen level of environmental quality, which can provide a benchmark for ESIAs.

Another key consideration for SEAs in port environments is their large economic, social, and environmental footprint often extending beyond the boundaries of the port site. For example, port development strategies should be understood by adjacent urban planning authorities so that such development is placed in context of their sustainable spatial development strategy (Wright 2002).

Although SEAs may not yet be a legislated requirements for port development in the WIO region, the value of undertaking SEAs in a more integrative manner in port planning is growing internationally (Deloitte Inc. 2015). For example, in the Port of Dublin a decision was made to undertake a SEA concurrently with the port master planning process (Dublin Port Company, 2012a, 2012b). Because the SEA process commenced at the early stage of the master planning, potential environmental effects of various planning scenarios, and their future implementation, could be proactively incorporated into the official master plan, rather than having to address such impacts retrospectively (Taljaard et al. 2021).

6.2.2 Environmental & Social Impact Assessment

The primary purpose of Environmental and Social Impact Assessments (ESIAs) is to determine and evaluate the environmental implications of development and to inform decision-making at the project level (Jay et al. 2007). This anticipatory, participatory environmental approach supplies decision makers with an indication of the likely environmental consequences of their actions, with the aim of supporting environmentally sound development (Fisher 2003; Jay et al. 2007). A comparison of the difference in emphasis between SEA and ESIA is provided in Table 6.3.

Table 6.3: Comparing differences in emphasis between SEA and ESIA (Source: DEAT 2004)

STRATEGIC ENVIRONMENTAL ASSESSMENT	ENVIRONMENTAL & SOCIAL IMPACT ASSESSMENT
Pro-active and informs development scenarios	Reactive to a development proposal
Used to assess effect of existing environmental and socio-economic conditions on development opportunities and constrains	Used to assess effect of a proposed development on environmental and socio-economic conditions
Relates to areas, regions or sectors od development	Relates to a specific project
Enables the development of a framework against which positive and negative impacts can be measured	Enables identification of project-specific impacts
Process aimed a development of a sustainability framework to inform continuous decision-making over a period	Well-defined beginning and end and focus on informing specific decision at a particular point in time
Focused on maintaining a chosen level of environmental quality and socio-economic conditions (e.g., identification of sustainability objectives and limits of acceptable change)	Focused on mitigation of negative impacts and enhancement of positive impacts
Wide perspective and includes low level of detail to provide vision and overall framework	Narrow perspective and includes high level of detail

The importance of addressing and assessing environmental impacts of port development (project level) is widely acknowledged. In 1990 the World Bank prepared a Technical Paper: *"Environmental considerations for port and harbour developments"* to aid port authorities in less developed countries to appreciate the full range of topics to be considered in dealing with environmental aspects of their ports and harbours (World Bank 1990). This was followed by a United Nations publication in 1992: "*Assessment of environmental impact of port development – A guidebook of Environmental Impact Assessment for port development*". This guide was intended to provide port planners with basic practical information on ESIA of port development, specifically in the Asia Pacific countries where port developments were rapidly growing at the time (UN 1992). Today ESIA for port development at project level is a common practice and is a legal requirement under national-level ESIA legislation in most countries.

A key principle that has been adopted to evaluate desirability of outcomes from environmental assessments, such as ESIAs is the hierarchy of 'avoid, mitigate, offset' (e.g., GHD 2013), that is avoiding impact; mitigating impact; and, finally, in the case of unavoidable impacts that can't be fully mitigated, to develop and implement offsets to compensate for losses. Ongoing adaptive management (i.e., systematic process for continually improving practices through learning) is an underlying principle.

ESIAs are legal requirements in most countries in the WIO region, typically triggered during project design stages in the case of ports (e.g., port expansions or new port developments). However, studies are often only initiated in the final engineering design stages severely limiting opportunity for environmental considerations to be integrated into early engineering designs. Mitigation measures then become piecemeal and often cannot address environmental issues holistically. This leads to conflict as mitigation measures are not acceptable to environmental lobbies and can lead to ports losing their societal licence to operate. This is illustrated locally in the case of the Port of Durban, where public dissatisfaction with development proposals and recommended mitigation measures from the ESIA have resulted in delays and even denials of environmental approvals. Consequent delays in development have had serious implications for project costs, national trading efficiencies and knock-on financial losses to the wider economy (Taljaard et al. 2021).

Importantly, the inclusion of environmental aspects in early engineering design stages further allows for consideration and inclusion of innovative design concepts aligned with the principles of 'Building with Nature' and 'Ecological Engineering'. The concept of 'Building with Nature' was proposed in the late 1970s by the Czech hydraulic engineer Svašek and introduced to the field of coastal engineering in the late 1990s by Waterman (Waterman et al. 1998; Waterman 2010). In essence, it underpins the concept of ecological engineering, and emerged in response to the growing need for coastal engineering practice to provide for human welfare while still protecting natural ecosystems and the benefits to society (Bergen et al., 2001). Specifically, it requires the integration of environmental and societal systems as early as possible in the design stages of coastal infrastructure (de Vriend et al. 2015; de Vriend and Van Koningsveld 2012; Vikolainen et al. 2014). The concept of 'Ecological Engineering' or 'Ecological Enhancement' (often referred to as Building for Nature) relates to the adaptation or modification of infrastructure to increase or improve habitat for endemic marine plants and organism, while still protecting human health and safety (Taira et al. 2020; Hall et al. 2018; MacArthur et al. 2020).

6.2.3 Environmental Management Systems

Environmental Management Systems (EMS) are regulatory structures developed within organisations rather than being regulated by governments, aimed at pro-active and systematic continuous environmental improvements. Specifically, EMS provides a structured framework designed to achieve continual improvement beyond regulatory compliance to improve efficiency, reduce costs, and minimise negative impacts on human health and the environment. These frameworks address policy making, assessment, planning and implementation of actions, incorporating considerations and decision making into day-to-day operations, but also strategic planning (Darnall and Edwards 2006).

EMSs typically consist of an environmental policy and stipulate evaluation processes to be undertaken to assess environmental impacts, establish and implement goals, monitor achievements and review planning and management practices (Lamprecht 1997). Studies have shown the value of well-designed EMSs for environmental performance and technical and organisational innovation, but the degree to which these systems provide strong, competitive benefits, depends on the extent to which the EMS permeates into organisational planning and management frameworks (Iraldo et al. 2009).

Benefits of EMSs (US-EPA 2007) include:

- Improved environmental awareness, compliance, and performance
- Reduced costs and improved operational efficiency through more efficient use of materials, operational streamlining, and strategic direction setting
- Reduced risk and liability, and improved security and emergency response capability
- Improved internal communication and cooperation, including between port authorities and terminal operators

- Enhanced credibility, public image and public confidence, as ports monitor and report performance and position themselves as leaders in environmental protection and management.

While each EMS is unique to an organisation's culture and priorities most follow the Plan-Do-Check-Act model. This model establishes a framework to examine and prioritise the environmental aspects of an organisation, then develops, implements, monitors, reviews and revises environmental programs and procedures to continually promote sound management and improvement. Importantly, an EMS should naturally leverage and build upon existing good practice and the practical knowledge base of employees throughout the organisation (US-EPA 2007).

EMS have been officially endorsed in many parts of the world. They have received recognition through, for example the International Organisation for Standardisation Standard (ISO) 14001 which provides a means of external certification. Such certification through EMS processes within ports is a growing trend aimed at demonstrating environmental compliance and commitment to continuous improvement of port environmental performance (Hossain 2018). Many ports already have components of an EMS in place, such as written and unwritten procedures, best management practices (BMPs) and regulatory compliance programs. Prominent EMS methods applied in ports worldwide include the International Organisation for Standardisation (ISO) 14001 standard (Brouwer and van Koppen 2008; Rebelo et al. 2014; ISO 2020a), the Eco-Management and Audit Scheme (EMAS) (Petrosillo et al. 2012; Testa et al. 2014), EcoPorts (Darbra et al. 2004, 2005; ESPO 2012a, 2012b, 2020) and the World Association for Waterborne Transport Infrastructure (PIANC) Environmental Management Framework (Whitehead 2000).

6.2.4 Sustainability Assessment

Given the nature of sustainable development, sustainability assessments are necessarily complex and multidisciplinary appraisal methodologies, and are conducted to inform decision-making and policy development (Sala et al. 2015, Villenieve et al. 2017). Various sustainability assessment tools have been developed including the Sustainable Development Analytical Grid, which is recognised by the UN and is part of their SDG Acceleration Toolkit (UNDG 2019). Globally, sustainability assessments are finding their way into port management (e.g., Pope and Grace, 2006; Lu et al., 2012; Schipper et al., 2017). Recently thy have begun to include the SDGs of Agenda 2030 (e.g., Nitsenko et al. 2017). In South Africa, commercial ports are being included in national transport related sustainability assessments, albeit at a broad scale (e.g., Transnet 2020). Table 6.4 summarises a list of key indicators for sustainable ports distilled from the international literature (e.g., Chen and Pak 2017).

Table 6.4: Examples of performance indicators for sustainable ports

SUSTAINABILITY OUTCOME	INDICATOR	SUSTAINABILITY OUTCOME	INDICATOR
Liquid pollution management	• Fuel spill contingency plan • Ballast water pollutant control • Cargo spill control and prevention • Sewage treatment • Solid waste dumping management • Dredging sediment disposal • Monitoring system for water pollution • Regulations on liquid pollution management • Hazard waste management • Encouraging use of watersaving facilities	Low-carbon and energy-saving management	• Using substitute energy and energy-saving devices • Using current technology for applied cranes • Applying new energy-saving operational processes • Using renewable energy resources, such as solar heat and wind power • Smart lighting within port terminals • Using on-deck power • Using afterheat for heating system
Air pollution management	• Reducing speed after landfall • Encouraging the use of low-sulfur fuel • Regulations on emissions of toxic gas • Encouraging public transport mode development • Cold ironing	Marine ecological protection and biology system preservation	• Wetland and marine habitat preservation • Reducing infrastructure disturbance to • marine biology density • Port entrance sediment and coastal erosion control

SUSTAINABILITY OUTCOME	INDICATOR	SUSTAINABILITY OUTCOME	INDICATOR
	• Annual plan for air pollution management • Dust control • Tree planting in port areas • Monitoring system for air pollution		• Encouraging participation in community's environmental protection/tree planting in port area
Noise control	• Monitoring system for noise level • Regulations on noise control • Reducing noise and vibration from cargo-handling equipment and vessels • Avoiding disturbance to community during infrastructure construction and expansion	Establishment of green port organizational management	• Training or education for employers at the operational level • Establishing managerial organization for green port development/ issue annual green port reports • Promote greening ports to the public • Maintain good communication with local government • Making the green port concept part of the corporate culture • Having regular and exclusive budgets for green port performance • Establishingenvironmental management and energy management information systems

The concept of 'Sustainable Ports' builds on that of 'Green Ports' and includes considerations of social sustainability, advocating the need for port development to balance economic growth, environmental protection, and social progress to secure its long-term future (Hiranandani 2014). Sustainability assessments applied in the port sector typically consider all three aspects of the Triple Bottom Line framework; Environment ('Planet'), Economy ('Profit') and Social ('People') (e.g., Schipper et al. 2017; Stein and Acciaro 2020), while other differentiate 'Institutional' aspects from the 'Social' grouping (e.g., Laxe et al. 2016).

- Economy: To achieve economic viability and long-term growth, contributing to socio-economic development
- Environmental: To protect natural resources and optimise natural resource management
- Social: To contribute to the wellbeing of people respecting their participation in decision-making
- Institutional: To ensure transparent and independent governance, where decisions are carried out according to objective criteria, in a framework that ensures the development of the above dimensions.

Following a comprehensive, systematic review of international literature covering sustainability assessments in the port sector, Stein and Acciaro (2020) proposed a set of qualitative measures for measuring corporate sustainability in ports. The framework conceptualises various external factors which influence, and often constrain, port business activities, such as regulation, macroeconomic conditions, port governance and societal perceptions. Shaped by these external factors, port business activities take place, with economic, social and environmental consequences which are accounted for in the Triple Bottom Line framework. The outcome of these consequences ultimately determines if a port can be sustainable in the long term.

Schipper et al. (2017) proposed a set of indicators considered suitable for application in port sustainability assessments which they embedded in a Sustainable Integrated Condition Index for ports derived from a more extensive global list (Table 6.5). In their index a concept of sustainable port growth is assessed through three common fundamental aspects: society, environment and economy, or "People", "Planet" and "Prosperity" (PPP), an approach that is increasingly incorporated in the businesses of financial institutions.

Table 6.5: Examples of key performance indicators (KPIs) for various PPPs and key performance indicators (Schipper et al. 2017)

ASPECT (PPP)	KEY PERFORMANCE INDICATORS
Social ('People')	Employment (# jobs)
	Well-being (human rights, education)
	Climate robustness
	Safety against flooding
	Urbanisation (accessibility and leisure attractiveness)
	Regulation of water pollution
Environmental ('Planet')	Water quality; Eutrophication
	Biodiversity loss of abundance and on biotopes
	Air quality
	Habitat destruction; loss of benthos, and extraction
	Emission of greenhouse gasses
	Energy consumption
	Sediment quality
	Erosion, sedimentation, maintenance dredging
	Water purification (per m^3 per capital)
	Ballast water treatment
Economic ('Profit')	Cargo growth (TEU)
	Cruise tourism (# passengers)
	Investments, fisheries, benefit, market share
	Traffic: railways, RoRo traffic, seagoing vessels & Hinterland connection
	Quality of handling

Within the WIO region, the To assist port authorities to monitor their performance in achieving sustainability outcomes, as defined in terms of the UN's Sustainability Development Goals [SDGs), South Africa's Council for Scientific and Industrial Research (CSIR), in consultation with researchers from the Technical University of Delft (Netherlands) and South Africa's national port authority developed a Sustainability Performance Index (SPI) for Ports (Taljaard and Weerts, 2023) to track the efficacy of port planning and management initiatives in achieving long-term sustainability. This tool is discussed in greater detail in the *Toolkit for sustainable port development in a Blue Economy* (UNEP et al. 2023b).

6.3 Sustainable Port Tools and Technologies

In addition to pro-active environmental assessment processes that can be implemented in support of sustainable port development there is an array of other tools and technologies that have been developed to promote sustainable port development. These have been variously categorised. For example, Bjerkan and Seter (2019) categorised these into (i) port management and plans, (ii) power and fuels, (iii) sea activities and (iv) land activities (Table 6.6).

Table 6.6: Categories of sustainable port tools and technologies (Source: Bjerkan and Seter 2019)

CATEGORY	ACTION
Port management and plans	• Port plans • Management of environment and energy • Monitoring • Concession agreements • Modal split • Port dues • Collaboration • Other managerial policies
Power and fuel	• Wind energy • Solar energy • Wave and tidal energy • Geothermal energy • Electrification • LNG • Biofuels • Methanol and hydrogen • Low sulphur fuels

CATEGORY	ACTION
Sea activities	• Speed reduction • Efficient vessel handling
Land activities	• Technological shift: trucks and drayage • Modal shift • Efficient truck operations • Efficient loading/unloading • Automation and intelligence • Clean industrial activity

Chui et al. (2014) organised sustainable port technologies into (i) environmental quality (ii) use of energy and resources (iii) waste handling (iv) habitat quality and greenery, and (v) social participation (Table 6.7).

Table 6.7: Categories of sustainable port tools and technologies, including sub-components (Source: Chui et al. 2014)

CATEGORY	COMPONENT	ACTION
Environmental Quality	Water pollution	Dredge monitoring and assessment; Investigate sewage source; Monitor water quality; Handle spill oil emergency; Install palisade on sewage pipe; Manage ballast water; Handle on board sewage; Improve the standard of ship's sanitation equipment
	Air pollution	Set up air quality monitoring system; Set up sulphur and nitrogen emissions control area; Provide shore power; Use energy from renewable sources; Use more electric machines/equipment; Use automated gateway system; Install air filter on port machines; Port machines use clean fuel with lower sulphur content; Monitor dust levels; Implement dust and smoke recycle measures; Monitor smoke from vessels; Adjust the type of importing bulk cargo (e.g., replace coal splinter with block coal); Promote environment-friendly transport; Promote port ride share or use shuttle bus; Establish the carbon footprint; Vessel speed reduction in port; Idle control on vehicles and cargo handling equipment; Idle truck parking arrangement; Use lower air pollution truck; Replace or improve the old vehicles; Vehicles and vessels to use clean fuel with lower sulphur content
	Noise pollution	Set high standards of noise limits; Monitor noise levels during construction and operation; Require to use lower noise; Install double insulation windows and boards; Use noise reduction machines (forklifts, ships, trucks, and other devices vehicles)
	Land, and sediment pollution	Remediation of contaminated sites; Reuse of dredge sediments; Sediments deposited in the separated area
Use of energy and resources	Material selection	Adopt LEED standard for green building; Procure locally available materials and suppliers; Use reusable materials for building/facility; Encourage using environment-friendly materials; Port landscaping to use local native species
	Water consumption	Reduce waste of drinking water and irrigation; Monitor water usage and leakage; On-site water treatment and reuse
	Energy usage	Use new environment-friendly energy in office and port area (e.g., solar power); Microclimate design; Use energy efficient control system; Use "heat stop" paint to coat the refrigerated containers; E-document program; Use energy efficient light
Waste handling	General waste	Recycle publications or office waste; Reduce packaging use and choice fewer packaging use supplier; Provide a dedicated storage area for recycling; Reuse the construction waste materials; Garbage classification in port area; Vessel waste classification
	Hazardous waste	Separate hazardous goods and poisons during construction and operation; Employ licensed contractor to handle hazardous waste; Sterilizing and burning of cargoes coming from epidemic area
Habitat quality and greenery	Habitat quality maintenance	Establish indicators of habitat quality; Ecological monitoring in port area; Establish compensation area or alternative area; Expansion of tidal areas for habitat restoration
	Port greenery	Grow flowers or trees in port area; Use biological spectrum lighting; Use nonchemical composition of pesticide and fertilizer
Social participation	Community promotion and education	Allow public to have port tour; Provide job opportunity; Encourage public participating in port planning; Provide green port web site; Promote green port concept for the community; Public opinion survey
	Port staff training	Hold green port seminars; Provide green facilities/building guide and training; Implement an accredited EMS; Provide green port training

In their guidance to port authorities on sustainable port development the World Association for Waterborne Transport Infrastructure (PIANC) identified 13 key issues (or categories) that require attention (Table 6.8).

Table 6.8: Categories of sustainable port tools and technologies, including options and technologies (Source: PIANC 2014)

CATEGORY	OPTION	TECHNOLOGIES
Land use planning	• Participation of stakeholders at specific stages of planning process to avoid later disruptions, conflict, and misunderstandings • Integrate related aspects into strategies such as regional and local planning, culture, environment, industry, society, tourism, and economics, as well as any policies that may have a direct or indirect impact on port development • Adopt Working with Nature philosophy where natural system is promoted to be central in technical design (www.pianc.org/workingwithnature.php).	• GIS-based spatial and environmental planning • Land-value calculators including valuation of nature • Checklists covering broad sustainable framework to ensure most issues have been addressed during planning phase • 'Serious Gaming' options to involve stakeholders/clients more

CATEGORY	OPTION	TECHNOLOGIES
Modalities and connectivity	• Strategic planning of hinterland transport • Develop dry ports or dedicated infrastructure • Integrated port community system • Demand modal splits in concession/lease contracts • Promote water transport option for links with hinterland	• Port strategy planning • Traffic management optimising traffic flows
Air quality	• Include requirements in contracts and lease agreements • Encourage responsible behaviour of tenants • Encourage and reward innovations and green technologies • Install monitoring stations (including a reference station) • Prepare action response plan	• Physical barriers that stop or reduce dispersion of air pollutants (dust) (e.g., contained spaces, control technologies, tree belts, specially designed barriers that bind pollutants • Treatment mechanisms for external storage of bulk products to minimise dispersion • Onshore Power Supply/cold ironing • Initiate financial programmes involving differentiation of port dues aimed at reducing emissions • Industry driven incentive programme
Surface water and sediment quality	• Tenant outreach and education • Prepare water resource action plans • Consider estuarine or river basin-scale approaches to deal with sediment and water quality	• Intercept water run-off and storm water treatment plants specific to ports areas • Artificially controlling (heightening or lowering) ground water tables and designing • Drainage trenches that allow for discharge of contaminated water • Designing sediment traps to capture contaminated sediment • Ecological optimisation of port infrastructure (such as artificial reefs of old quay wall structures or wetlands of clean dredge material) • Plan and design storm water catchment basins to be used in port operations after treatment • Set up an integrated monitoring system • Develop and gather information (best practices) through specialised knowledge platforms
Soil and ground quality	• Clauses in concession agreements stating land to be returned in same state as at onset of lease. • Identify sources and prepare source control programmes to stop and/or mitigate pollution • Prepare regulations and reserve port capacity (enforcers) to ensure enforcement of regulations. • Clear and continuous reporting of monitoring results.	• Infrastructural and technical measures such as sealed floors, containment, automatic valves and high-level alarms, leak detection systems • Working procedures/regulations for fuelling of equipment and other activities involving transfer of hazardous liquids • Mega site approaches and redevelopment of industrial areas, which combines management of historic groundwater pollution for larger port areas (integrated approach) • Risk based approach of contaminated groundwater, based on dominant receptors
Dredging impacts	• Prepare sustainable dredged material management plan • Invest in ESIA to identify impacts • Implement realistic dredge permit conditions and best management practices • Monitor dredging activities to test and demonstrate effectiveness • Set up a strong communication programme including stakeholder involvement	• Design harbour basins based on hydraulic models minimising inflow of sediments • Implement overall sediment management reduction plans • Flattening out of high spots in berth • Organise tests to determine actual nautical depth in ports that have fluid mud • Implement and develop technologies to beneficially reuse material
Sound impacts	• Develop acceptable sound contours based on measurements • Work with sound budgets with the different users • Noise mapping • Zoning of activities by planning noisy activities away from potential receptors • environmental management plans for in-water construction	• Develop, test and implement sound prediction models • Consider alternatives such as silent asphalt, linking activities to meteorological conditions (wind direction), silent tyres, electric cars, etc. • Stimulate and implement noise reduction technology • Use sound absorption building materials • Piling during port construction and piling: slow start to give species a change to escape
Energy and climate change mitigation	• Greenhouse gas emissions inventory and goals • Energy conservation measures • Improve efficiency within logistics chain • Join World Ports Climate Initiative (WPCI) • Energy management plans • Controlled (sectional) warehouse heating, cooling, and lighting	• WPCI Greenhouse Gas Toolbox • WPCI Carbon Foot printing Guide for Ports • WPCI Carbon Calculators • On-Port Renewable Energy
Climate adaptation	• Assess facilities, identify the vulnerabilities, and proactively reinforce	• Modelling –informs infrastructure investment given uncertainty of the rate of sea level rise and increase in storm surges • Natural defences: create oyster reefs that grow with sea level rise and protect shorelines and • Protecting – constructing barriers
Habitat and species health	• Strategic planning include nature • Use eco-structures to create habitats for fish or other aquatic species	• Creation or maintenance of maritime access should start from a good understanding of system • Design new harbour basins and port areas taking ecosystems into account
Landscape management and quality of life	• Prepare visual impact assessment	• Visual simulations are tools • Colour: Building colour visually compatible with the surrounding landscape • Visual Screening (e.g., planting) • Earth Mounding or Bunding - effective short term amelioration measure

CATEGORY	OPTION	TECHNOLOGIES
Ship-related waste management	• Port waste management plan • Delivery incentive schemes: cost recovery systems should provide financial incentives for ships • Data collection and monitoring, and enforcement • Incentives to ships and vessels to sort their waste in different fractions to ease recycling	• Development of port reception facilities • Waste handling characteristics (incl. equipment and storage) • Types of cargo handled in port • Design of port reception facility • Information and monitoring systems
Sustainable resources management	• Provide forums for companies to exchange information on closing material loops • Collect and disperse practical information on co-operation and material exchange • Incentives (deduction of concession charges) to encourage sustainable resource management • Obligatory minimum levels of material re-use for new companies • Park management	• Close the gap/Umicore project with WEEE • Material management of dredged materials

Maritz et al (2014) organised technologies into (i) environmental quality (ii) environment construction, and (iii) resource management (Table 6.9).

Table 6.9: Categories of sustainable port technologies, including sub-components (Source: Maritz et al. 2014)

CATEGORY	SUB-COMPONENT
Environment quality	• Environmental quality in port • Carbon dioxide emission • Water quality • Land use • Environmental management
Environment construction	• Expansion of planting • Green building • Comprehensive e-services • Wireless network in port
Resource management	• Material selection • Management of waste • Water resource • Energy use • Transportation

Lam and Notteboom (2014), based on study covering four international ports (Antwerp, Shanghai, Singapore, and Rotterdam) identified and organised sustainable port technologies and tools into (i) penalty pricing (ii) incentive pricing (iii) monitoring and measures, and (iv) market access control and environmental standard regulations (Table 6.10).

Table 6.10: Categories of sustainable port technologies and tools, including examples (Source: Lam and Notteboom 2014)

CATEGORY	SHIP TRAFFIC	CARGO HANDLING AND STORAGE	INTERMODAL CONNECTION	INDUSTRIAL ACTIVITIES	PORT EXPANSION
Penalty pricing	• Surcharge to docking fees • Fines on marine oil spills		• Fines for non-compliance with agreements on modal shift	• Fines on pollution damage to marine environment by dumping of wastes	• Fines on pollution damage by construction projects
Incentive pricing	• Ships meet Environmental Ship Index Scores grated discount on GT section			• Financial incentives for companies that carry out energy audit	
Monitoring and measure	• Ship GHG emission	• Crane GHG emission • Vehicle GHG emission • EMS • Sustainability Report	• Monitoring and analysis of policy developments • Sustainability report	• Quality of dock water • WQ monitoring • Sustainability report	• Ecological port design and construction
Market access control & environmental standard regulations	• Sulphur fuel cap • GHG emissions • Regulations on oil pollution casualties • Regulation/control on pollution damage to marine environment by vessels	• Cargo handling vehicles with sulphur fuel limits • Terminal concession criterion on sustainability • Regulated operation activities	• Agreement on modal shift (terminal operators and port authority)	• Regulation on marine pollution by dumping of wastes • CO_2 reduction	• Regulation on pollution damage to by construction projects • Approval from government authorities

Ares Moreno (2018) organised specific sustainable port goals and key considerations into various port development stages (Figure 6.1) (Table 6.11).

Table 6.11: Specific sustainable port goals and considerations associated with various port development phases (Source: Ares Moreno 2018)

DEVELOPMENT PHASE	ASPECT	GOAL	CONSIDERATIONS
Planning	Port's mission	Green port purpose	• Definition of objectives & sub-objective
		Green strategy	• Definition of strategy & action plans
		Green standards & behaviour	• Definition op policy
		Green values	• Definition of driver values
	Site selection	Biodiversity conservation	• Impact on protected areas • Impact on protected species • Impact on natural habitats
		Minimum negative environmental impact	• Use of existing port facilities • Use of existing hinterland connection • Use of natural conditions • Impact on coastal processes Impact on water system quality
		Minimum negative social impact	• Buffer area to local communities • Impact on existing recreational areas • Necessity of resettlement of communities Impact on archaeological cultural values • Employment opportunities to local communities • Impact on fisheries and aquaculture • Impact on existing economic activities
	Master planning	Efficient port layout	• Productivity • Flexible layout and adaptive planning • Use of land given type of soil, volumes, and quality • Compensation measures • Distribution of port terminals considering communities • Use of common infrastructure & facilities • Use of waterfront and water depths • Use of environmentally friendly transport solutions
		Integration into surroundings	• Integration of the port into the urban or natural environment • Connectivity
		Added value	• Conservation areas • Recreational areas • Inclusion of social and economic aspects
Design	Infrastructure	Minimum negative environmental impact	• Use of Onshore Power Supply technology • Electrification of terminals • Measures for mitigation of environmental accidents risks • Impacts on communities • Impacts on coastal processes • Use of carbon capture technology
		Future proof	• Flexible and adaptable design
		Added value	• Inclusion of ecological and nature enhancement measures
	Materials	Efficient use of material	• Use of resources • Reuse of material
		Materials selection based on sustainability	• Source of materials • Nature of materials • Performance characteristics of materials
		Efficient waste management	• Waste management plan • Handling of hazardous waste
	Energy	Energy efficiency	• Energy consumption • Use of renewable energies
Construction	Maritime works	Environmentally friendly construction methods	• Processing of contaminated material • Impacts assessment • Increase of turbidity • Occurrence of spills • Use of overflow • Impact on groundwater quality • Disposal of material
		Equipment selection based on sustainability	• Environmental performance of equipment
	Earth works	Environmentally friendly construction methods	• Construction plan • Impacts on communities
		Equipment selection based on sustainability	• Environmental performance of equipment
Operations, maintenance, management	General	Pro-active port Authority role	• Acceptance of terminal operators or companies • Acceptance of cargo • Cooperation between companies
		Sustainable hinterland transport	• Use of electric trucks • Implementation of an environmental zoning
		Energy and resources efficiency	• Lighting system • Reuse of resources • Operational efficiency
	Terminals	Hazardous material management	• Spills prevention • Emergency response plan
		Sustainable yard equipment	• Environmental performance of equipment
		Efficient waste management	• Amount of waste • Waste processing and disposal
	Vessels	Emission reduction	• Acceptance of vessels • Port dues and rewards • Measures for emissions reductions

DEVELOPMENT PHASE	ASPECT	GOAL	CONSIDERATIONS
		Ballast water management	• Ballast Water and Sediments Management Plan
	Environmental management systems	Continuous cooperation with stakeholders	• Inclusion of stakeholders to set goals and contribute with ongoing efforts
		Sustainability reporting	• Development of sustainability reports as a strategy for improvement
		Control systems and monitoring	• Setting of a monitoring program to verify compliance with green objectives and targets
		Continuous improvement	• Searching for improvement and optimization of operations, maximizing productivity, and eliminating sources of inefficiency
		Stimulation of green technologies and innovation	• Looking for opportunities for implementation of green technologies or innovative solutions

Others have based categorisation on interventions, for example (i) technical infrastructure, (ii) pricing and access, and (iii) integrated management approaches (Lawer et al. 2019) (Table 6.12).

Table 6.12: Categories of sustainable port tools and technologies (Source: Lawer et al. 2019)

CATEGORY	ACTION
Technical infrastructures	• Cold ironing (e.g., addressing vessel emissions): Otherwise also known as onshore power supply (OPS), cold ironing is a land-to-ship technology that provides shore-side electricity connection derived mainly from renewable sources • Waste reception infrastructure: Marine litter and pollution is a major environmental problem and as such the provision of a port reception facility has been identified as a green port measure • Cargo handling and transport: Measures involve switching or converting from carriers, hybrid vehicles, trailers, tractors and forklift trucks and cranes that use diesel fuels to those that use biofuels or renewable sources • Greenhouse gas emission inventory: This tool requires the development of a structured inventory of energy and fuel use and other activities that produce greenhouse gas emissions at the port. • Handling of hazardous waste: Efficient handling of hazardous or port and ship generated waste • Ballast water handling: Reduce impacts pertaining to e.g., invasives • Digitalisation: Use of a single window and port community system to service ships and land transport including other stakeholders (one-stop-shop), paperless business and operations, digital connectivity technologies and data analytic, utilising blockchains, and cyber security measures
Pricing and access	• Environmental shipping index (ESI): It is a market-based tool to help improve the environmental performance of seagoing vessels visiting ports • Concession agreements: Environmental sustainability is made a requirement for granting concessions to companies that want to operate at the port, e.g., cap on CO_2 emissions during terminal lease agreements, to encourage terminal operators to embrace innovation and to meet environmental objectives of port authority • Port dues: As ships, trucks and carriers pay several fees for using port infrastructure, port dues involve the use of incentives and punitive measures to promote environmental protection following the polluter pays principle
Integrated management approaches	• Environmental management systems (EMS): Based on an internationally recognized environmental management standard promoted as a priority green port tool (see Chapter 6.2.3) • Nature compensatory mitigation (trade-off) sites: Tool is the creation of nature compensatory mitigation sites in port or another location to give to nature what has been taken elsewhere in the case of unavoidable impacts of port construction • Dedicated department responsible for handling environmental issues: Providing skills training for staff to equip them with capacity to handle new trends in environmental management, and adopting collaborative mechanisms with port stakeholders in implementing environmental policy

Alamoush et al (2021) provided a more holistic categorisation of sustainable port tools and technologies across all three dimensions of port sustainability, that is environmental, social, and economic (triple bottom line) (Table 6.13).

Table 6.13: Holistic categories of sustainable port tools and technologies, including environmental, social, and economic (Source: Alamoush et al. 2021)

DIMENSION	COMPONENT	SUB-COMPONENT	ACTION
Environmental	Air pollution management	Air emission reduction	• Establish emission inventory and energy consumption • Monitoring of CHE, ships', and trucks' emissions • Replacement of polluting equipment or engine exchange (with cleaner ones) • Electrification, hybridisation of CHE (e.g., electric RTGs for containers and shore-side pumps for bulk liquids) • Use of emission reduction/control technology (pre-after treatment retrofit), such as the Diesel retrofit technologies (Diesel Oxidation Catalysts, Diesel Particulate Filters or Selective Catalytic Reductor) • Use of low-sulphur fuel and renewable alternative fuels (hydrogen, LNG, ammonia, renewable diesel, and methane) • Promote public and environment-friendly transport (employees' sustainable mobility through shuttle bus, carpooling, cycling) • Onshore power supply (OPS) for ships (e.g., for energy intensive cruise and containers • ships), and tugboats and pilot boats when stationary and idling • Providing power supply (charging stations) for electrified trucks • Provision of alternative fuel bunkering for ships (e.g., LNG) • Reduce truck congestion (e.g., using off-dock staging yards and chassis, building dry ports and inland depots, manging truck empty return, and utilising the Authorized • Economic Operator System, automatic clearance and extended gate hours) • Reduce trucks' emissions through ban of old trucks, terminal appointment system

DIMENSION	COMPONENT	SUB-COMPONENT	ACTION
			(TAS), truck identity card, traffic mitigation fees, and off-peak traffic shift • Enforce modal split (from road to rail, inland waterways and pipeline) • Manage motorways of the seas
		Dust and odour reduction	• Utilise dust and smoke recycle measures (e.g., for dry bulk ships) • Build physical barriers to stop/reduce dispersion of air pollutant (e.g., tree belts, walls) • Minimise Volatile Organic Components (VOC) emitted during loading and unloading operations (liquid bulk ships)
	Water pollution and waste management		• Control, prevent and monitor spill of cargo and oil during loading and unloading and disconnection of pipelines, and from engine oil and lubricants • Seal sewage tanks and monitored. • Use swales, storm filters, cyclonic devices, and planters can be utilised to improve stormwater runoff quality • Floating or mobile reception facilities with the ability to collect, classify and separate various types of ship waste • Provide environmentally friendly services (e.g., ships' hull and propeller cleaning) and observe standard of ships' sanitation equipment • Oil spill contingency plans covering measures to be taken to prevent, control, and respond to any spill • Secure spillages by deploying booms and skimmers
	Noise pollution management		• Building noise map and zone noisy activities • Use standards for limitation of noise and vibration from CHE and construction (e.g., isolation of forklifts, trucks, vehicles, and tugs) • Insulate n of windows, doors, and fences • Building noise barriers around the port (e.g., concrete, trees, and earthen walls), • Sound absorption materials on buildings and walls • Use silent asphalt and tyres • Plan activities on basis of meteorological conditions (wind direction) • Use fish bubble curtains to mitigate underwater noise of dredging • Monitoring and characterise ships' noise (using sonars, echo-sounders, robotics, and hydrophones) • Dedicate protected areas, buffer zones, and corridors to keep ships away from rich marine environments • Implement slow steaming of ships and tugs, and utilise air bubble curtain technology to absorb shipping noise
	Visual pollution management	Light	• Use biological spectrum lighting to mitigate negative impacts
		Aesthetics	• Appraise visual impact of existent landscapes • Take advantage of existing topography and maintain low profile infrastructure and equipment
	Freshwater management		• Measures to conserve water and protect freshwater resources, e.g., set targets to reduce waste of drinking water, monitor water usage and leakage • Treat and use wastewater on-site • Recycle cleaning water for irrigation and cleaning, and harvest rainwater
	Marine biology conservation	Limit and treat sediment	• Reuse of dredging sediments • Control port entrance sediment and coastal erosion • Deposit (dispose) sediments in a separated area
		Avoid dredging destruction	• Monitor dredging operations (pre and after dredging sampling) • Source, lease and permit environmentally friendly dredgers • Remediation of contaminated sites and mitigation of turbidity
		Protect habitat quality	• Ecological monitoring and mitigation in port areas for habitat quality, preservation, and wetland restoration • Expansion of tidal areas for habitat restoration • Creation of local sanctuaries for birds and fish in and around port areas • Soil pollution monitoring • Buying, creating, selling, and banking ecological service credits to offset development impacts on wetlands • Establishment of buffer zones for endangered coral relocation • Fish bubble curtains along harbour entrances to keep fish out of dredging area • Monitor and control of ship's fouling (antifouling), and discharge of effluents
		Flood control	• Prevention of floods by proper training and using innovative technologies
	Hazardous cargo management		• Follow International Maritime Dangerous Goods (IMDG) Code • Separate hazardous goods and construction materials • Employ licensed contractors to handle hazardous waste
	Climate change	Adaptation	• Build walls and beach restoration • Protect against coastal erosion • Use climate change monitoring applications • Establishment natural defences, e.g., planting mangroves, and creating oyster • reefs that grow with sea level rise and protect shorelines and ports from high waves and erosion • Consider climate sensitive designs
		Mitigation	• Establish energy consumption inventory and carbon footprinting, including shipping and land transport • Use renewable energy technologies (wind, solar, ocean, geothermal) • Reduce energy consumption through insulation, coating, and painting of buildings, storage, warehouses, and using reefer sheds • Use after pre and after treatment technologies in CHE (e.g., Methane catalyst reductor) • Design energy efficient infrastructure through adopting LEED standard for green building energy efficiency designs (passive house concept), and microclimate models • Use LED lights and automatic sensors • Use energy efficiency technologies (e.g., smart grids, microgrids, smart load management, regenerative energy reclamation, virtual power plants, energy storage systems, energy saving tyres)

DIMENSION	COMPONENT	SUB-COMPONENT	ACTION
			• Eco driving, idle control and reduction, slow steaming, speed reduction • Control heat, ventilation, and air conditioning (HVAC) • Operational efficiency planning (e.g., cranes and yard planning) • Use biomasses to generate power and heat • Introduce carbon sequestration, capture and storage projects
Social	Employees rights		• Improve employee's welfare and health • Non-discriminative employment • Ensure gender equality and diversity in employment • Provision of continuous training and education • Maintain employees' job security
	Safety and security		• Monitor, control and minimise accidents and near miss incidents • Improve work security and safety • Implementation of ISPS code • Prepare disasters and incidents contingency plans • Prepare hazardous and dangerous materials storage plans, e.g. safe cargo handling according to IMDG Code • Improve safety of infrastructure and roads • Ensure safe and secure navigation for ships • Collaborate with supply chain members to minimise risks, and improve safety
	Community		• Support local employment (job opportunities) • Encourage public participation in port environmental projects planning • Recognise requirements of neighbouring community (e.g., public opinion survey) • Manage visual impact and improving city scenery • Mitigate value decrease in community real estate because of repellent operations (e.g., cargo pipelines, stockpiles, noise) • Expand corporate social responsibility to include communities (e.g., provision of scholarships, internships, and vocational training for locals, offering local tours, supporting economically local projects and tourism industry development) • Partner with academics/research institutions, e.g., for project evaluation • Report port sustainability through (GRI guidelines) and/or in port website
	Seafarers		• Facilitate seafarers' welfare by permitting port and city calls • Facilitate crew changes and repatriation • Ensure seafarers rights are well taken care of onboard calling ships
Economic	Economic growth		• Invest in port infrastructure • Establish port development funds • Attract foreign investment (public private partnership (PPP), concessions) • Invest in research and innovation
	Trade and logistics facilitation		• Support value added logistics activities • Maintain high quality and cost-efficient business services (e.g. efficient cargo handling and clearance) • Integrate with maritime supply chains • Improve ships Just-In-Time and virtual arrival • Support Just-In-Time import and export • Optimise port-ship-truck operations (e.g., use of terminal operating system for berth planning, and yard and equipment scheduling, planning, and allocation) • Automate cranes, including port trucks such as the use of Automated Guided Vehicle • Automate gates (automated gateway system) • Use automated mooring systems for ships • Streamline number of containers moves (throughput) • Improve truck and rail traffic, and inland navigation access • Facilitate and promote adequate (multimodal) infrastructure • Build and integrate dry ports and inland container depots
	Digitalisation		• Use single window and port community system to service ships and land transport including other stakeholders (one-stop-shop) • Employ paperless business and operations (e.g. electronic data interchange, E-document program, RFIDs) • Utilise digital connectivity technologies and data analytics (e.g., Internet of Things, and big data cloud, and edge computing) • Utilise blockchains (e.g., Digital Ledger Technology, electronic bill of lading) • Cyber security measures

The above review presents the vast array of sustainable port technologies and tools that have been developed internationally, as well as various approaches that have been applied in an attempt structure or organise these interventions. However, for any port, the geographical, political, operational, regulatory, financial and surrounding community settings will largely shape the site-specific priorities, and design of sustainability ports measures and actions (Alamoush et al. 2021).

6.4 Implementation Schemes

Implementation schemes refer to types of institutional mechanisms that port authorities can employed to facilitate effective implementation of sustainable port measures and actions by port operators and tenants, ships and land transport. These have been categorised into (Table 6.14):

- Regulations and standards *(ultimate backstop for sustainability and technological implementation)*

- Incentives and disincentives including grants
- Voluntary and compulsory agreements
- Training and information sharing.

Table 6.14: Categories and examples of implementation schemes for sustainable ports (Source: Alamoush et al. 2021)

CATEGORY	EXAMPLE
Regulations and standards	• International conventions and agreements (see Table 3.1) • National regulations and standards • Port specific standards and guidelines
Incentives and disincentives	• Indices to incentivise ship and port operators who implement safety, security, and environmentally friendly measures (e.g., environmental shipping index - ESI) • Extra tariffs on polluters to incentivise cleaner performance (Warning: Without uniform application disincentive can compromise port competitiveness)
Voluntary and compulsory agreements	• Voluntary agreements (e.g., speed reductions when approaching port, stakeholder involvement) • Compulsory agreements with port operators, ships, and land transport, through concession contracts and licences to operate, that must include sustainability actions and measures
Training and information sharing	• Outreach of sustainability awareness to employees, port operators, ships and land transport • develop training courses and seminars aim at changing behaviour toward better uptake of sustainability actions • Disseminate sustainability information and promote the green port concept (e.g., seminars) within surrounding communities

6.5 Addressing Funding Challenges

The primary focus of sustainable port development is environmental and social sustainability (e.g., Guo and Liu 2018). Although it has been argued that sustainable ports implicitly will lead to positive outcomes on their economic performance (Lam and Van de Voorde 2012; Alamoush et al. 2021), 'sustainable' best practice typically comes with higher costs, often making financial feasibility an obstacle because project financing is traditionally based on a short-term mentality (Ares Moreno 2018). This is especially relevant in developing regions of the world where public capital is often limited. Securing of dedicated financial resources, therefore, is critical for the effective planning and implementation of sustainable port development. Ares Moreno (2018) suggests a few possible supplementary financial resources that could be considered:

- Blended finance - strategically using development finance to mobilise additional finances towards sustainable port development in developing countries
- Investment from stakeholders - operators, municipalities or industries investing especially where there is added value
- Green Bonds – such as offered development banks (World Bank or Deutsche Bank).

Large banks, insurers, and investors often look for investment opportunities in sustainable development. United Nations Environment Programme Finance Initiative (UNEP FI), a partnership between UNEP and the global financial sector, advised these sectors to seek sustainable port development involving best practice pertaining to (www.unepfi.org/news/themes/ecosystems/5-examples-of-best-practice-to-sustainably-finance-the-port-sector/):

- Green transport
- Green technology
- Responsible spatial management (considering sensitive natural ecosystems)
- Green supply chains
- Emissions incentives.

7. RECOMMENDATIONS FOR WAY FORWARD

The WIO region supports a wide variety of ports and harbours, ranging from large commercial port to small fishing jetties. These infrastructure developments fulfil important socio-economic services, but they are invariably located in sensitive coastal areas which support rich natural resources that provide other valuable nature-based goods and services to adjacent communities. Ports benefit from ecosystem services provided by sheltered coastal environments, but they also contribute to an array of negative impacts on coastal ecosystems and other ecosystem services. This is well documented in the international literature. Environmental problems associated with port development and operations include climate impacts, air pollution, water, sediment and soil pollution, physical problems including destruction of habitat or biota, harmful or invasive marine organisms and pathogens, underwater noise, and artificial light. Numerous activities undertaken in ports contribute to these problems potentially causing negative impact on the environment and associated socio-economic benefits. To achieve sustainable port development these problems need to be identified and linked to the contributing activities to inform timeous management intervention and development and implementation of mitigating actions.

While environmental impacts of ports in the WIO region are clear, environmental data to quantify such impacts are very limited, or not readily available (e.g., published in the public domain). An assessment of global and regional geospatial databases on coastal habitats (e.g., mangroves, coral reefs, and seagrasses) in selected ports of the region revealed that most of these databases are not at suitably fine resolution to be used for local port development. Preliminary studies showed that remote sensing technologies such as Google Earth Engine (GEE) can provide suitable geospatial information for above ground habitats (e.g., mangroves), but more sophisticated technologies should be investigated to provide suitable geospatial data on other important coastal habitats, such as coral reefs, seagrasses and different substrate habitats (e.g., sand banks). For application and the local port scale resolution of spatial data should at least be 5 x 5 m (for strategic planning) and ideally at sub-meter resolution for detailed design and monitoring purposes.

It is recommended that development in the generation of high resolution ecological geospatial data be coordinated across countries in the region. Ideally, standard methods for the generation of such data should be developed and agreed upon. Doing so will enable the region to conduct comparative studies both spatially (across countries) and temporally (over time in specific ports). This could be achieved through the establishment of a Regional Network or a Community of Practice comprising data scientists and ecologists, the latter being key to assisting with ground truthing and interpretation of geospatial data. An underpinning requirement to successful develop and benefit from such data technologies is commitment from port authorities, in collaboration with other regional and national networks with interests in collating and applying high resolution ecological data, to invest in such endeavours. Investment should be pre-emptive, early enough in the port development cycle to ensure that negotiations pertaining to coastal habitat protection and/or trade-offs are incorporated in port (spatial) planning from the site selection stage. These data will also be valuable later, in the operational stages, to inform port environmental monitoring programmes. Even though geospatial data for port development will be focused on the spatial demarcation of the port space, it will be important to extend geographical boundaries of geospatial data layers to adjacent near-shore systems which influence, and are influenced by, ports and port activities. Examples are anchorage areas and adjacent shorelines that may be influenced by pollution or changes in sediment dynamics because of port structure and operations. Numerical modelling techniques to simulate oceanographic circulation and pollutant transport processes are useful tools that can be used to determine appropriate geographical boundaries.

Ports worldwide are increasingly under pressure to focus on more than just economic objectives. They are required to develop and implement resilient and sustainable strategies to include the environment and society. Whilst good progress has been made in some countries of the WIO region towards sustainable port development, it is critically important that the WIO region continuously draw and build on international advances to ensure sustainability of its ports, both existing and new. In the WIO region port developers and operators have the opportunity to define sustainable trajectories for new ports, or expansion in existing ports. Failing to do so will result in potentially detrimental impacts on critical coastal habitats and the resource base that future coastal livelihoods depend on.

This Situation Assessment provided an overview on the status of port development in the WIO region, as well as global environmentally related advances in sustainable port development. It motivates the promotion of sustainable port development in the WIO region. To this end the output from this assessment has been used to provide context to the other science-based outputs produced as part of this this project, namely:

- A Scenario Analysis evaluating generic development pathways which range from 'doing-nothing' to options incorporating 'sustainable port' considerations, drawing on information in the Situation Assessment providing context and backdrop for more sustainable port development in the WIO region.
- A Toolkit for Sustainable Port Development in a Blue Economy, comprising practical management and operational tools aimed at port developers and operators in the WIO region towards advancing sustainable port planning and operations aligned with applicable international best practice.
- A Policy Brief, capturing proposed recommendations for future sustainable port development in a blue economy in the WIO region.

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APPENDIX A: Summary of Documented Sea Ports and Harbours in WIO region

(Adapted from https://www.searates.com/maritime/; https://adnavem.com/world/eastern-africa; http://ports.com/browse/africa/)

COUNTRY	PORT	LOCATION (COORDINATES)	STATUS	HARBOUR TYPE/CARGO/HANDLING	RESPONSIBLE AUTHORITY (where data was available)
Comoros	Moroni	11°42'15.22"S; 43°14'53.23"E	Operational	Open Roadstead (very small)	Autorité Portuaire des Comores APC) Société Comorienne des Ports (SCP)
	Mamoudzou	12°46'42.35"S; 45°14'1.57"E	Operational	Coastal breakwater (small)	
	Pamanzi Bay	12°46'59.02"S; 45°15'14.05"E	Operational	Coastal breakwater (very small)	
	Mutsamudu	12°10'2.32"S; 44°23'30.52"E	Operational	Open Roadstead (very small, deep-water port)	Établissement Public Port Autonome de Mutsamudu
	Fomboni	12°17'27.31"S; 43°45'23.57"E	Operational	Open Roadstead (very small, pier)	
	Dzaoudzi	12°46'55.59"S; 45°15'32.18"E	Operational	Open Roadstead (very small)	
	Longoni	12°43'21.92"S; 45° 9'56.38"E	Operational		
Kenya	Mombasa	4° 3'16.78"S;39°38'41.25"E	Operational	Coastal Tidal Gate (medium, commercial)	Kenya Ports Authority (KPA)
	Lamu (new) (greenfield)	2°11'47.79"S; 40°55'50.84"E	Under construction, to be 2nd largest commercial port		KPA
	Lamu (old)	2°16'6.63"S;40°54'10.86"E	Operational	Small, fishing	KPA
	Malindi	3°12'54.24"S;40° 7'35.56"E	Operational	Coastal Natural (small, pier, fishing/tourism)	KPA
	Shimoni	4°38'55.05"S;39°22'48.47"E	Operational	Very small, jetty, fishing/tourism	KPA
	Kilifi	3°38'14.05"S;39°50'37.47"E	Operational	Open Roadstead (very small, jetty, fishing/marina)	KPA
	Takaungu	3°40'42.44"S; 39°52'8.34"E	Proposed, large land site in possession of KPA		KPA
	Ngomeni	2°59'39.06"S; 40°11'26.70"E	Proposed, potential to develop as 3rd commercial port		KPA
	Funzi	4°34'19.33"S; 39°26'2.62"E	Operational		KPA
	Vanga	4°39'37.44"S; 39°13'13.00"E	Operational		KPA
	Mtwapa	3°57'9.64"S; 39°44'26.56"E	Operational	Small, fish landing, smaller yachts	KPA
	Kiunga	1°44'46.20"S; 41°29'31.34"E	Operational	Small, fish landing, small volume of cotton & coconut export	KPA
Madagascar	Antalaha (PIN)	14°54'2.48"S; 50°16'56.86"E	Operational	Very small	PCG
	Andoany	13°24'8.57"S; 48°17'59.75"E	Operational	Open Roadstead (very small, jetty)	
	Antsiranana (PIN)	12°16'2.29"S; 49°17'20.39"E	Operational	Coastal Breakwater (small)	
	Ehoala (Fort Dauphin) (PIN)	25° 3'51.95"S; 46°58'1.50"E	Operational	Coastal Breakwater (small)	Port of Ehoala SA, subsidiary of Rio Tinto (private) (PCG)
	Mahajanga (PIN)	15°42'42.45"S; 46°17'53.54"E	Operational	Coastal Natural (very small)	
	Maintirano (PIR)	18° 4'41.40"S; 44° 1'36.40"E	Operational	Open Roadstead (very small)	Maritime and River Port Agency (APMF)
	Manakara (PIR)	22° 8'28.97"S; 48° 1'16.42"E	Operational	Open Roadstead (very small)	APMF
	Mananjary (PIR)	21°14'30.78"S; 48°20'44.69"E	Operational	Open Roadstead (very small)	Mananjary Port Authority
	Maroantsetra (PIR)	15°26'60.00"S 49°49'0.00"E	Operational	Open Roadstead (very small)	APMF
	Morombe (PIR)	21°44'29.82"S; 43°21'32.68"E	Operational		APMF
	Morondava (PIR)	20°17'39.31"S; 44°16'20.38"E	Operational	Open Roadstead (very small)	Morondava Port Authority
	Nosy Be (PIN)	13°24'27.50"S; 48°16'52.53"E	Operational	Very small	APMF
	Sainte Marie (PIR)	17° 4'58.89"S; 49°49'1.24"E	Operational		APMF
	Taolagnaro (Fort Dauphin) (PIR)	25° 1'39.21"S; 46°59'49.86"E	Operational	Open Roadstead (very small)	APMF
	Toamasina (Tamatave) (PIN)	18° 9'20.35"S; 49°25'25.82"E	Operational	Coastal Breakwater (small, major expansions underway)	Société du Port Autonome de Toamasina (SPAT) (PGA)
	Toliara (PIN)	23°22'41.22"S; 43°39'49.83"E	Operational	Open Roadstead (very small)	APMF

COUNTRY	PORT	LOCATION (COORDINATES)	STATUS	HARBOUR TYPE/CARGO/HANDLING	RESPONSIBLE AUTHORITY (where data was available)
	Antsohihy	13° 5'30.67"S; 48°50'39.26"E	Operational	Coastal Natural (very small)	
	Vohémar/ Iharana (PIN)	13°21'13.77"S; 50° 0'20.97"E	Operational	Coastal Natural (very small)	PCG
	Analalava	12°16'2.29"S; 49°17'20.39"E	Operational	Very small	APMF
Mauritius	Port Louis	20° 9'29.59"S; 57°29'48.15"E	Operational	Coastal Breakwater (small, expansions planned)	Mauritius Port Authority (Mauport)
	Mathurin (Rodrigues)	19°40'47.94"S; 63°25'11.99"E	Operational	Coastal Natural (very small, containers, passenger terminal)	Mauport
Mozambique	Maputo	25°58'32.02"S; 32°33'41.70"E	Operational	Lake or Canal (medium, commercial)	Maputo Port Development Company (MPDC) in partnership with Portos e Caminhos de Ferro de Mocambique (CFM)
	Beira	19°48'56.62"S; 34°49'58.92"E	Operational	Coastal Natural (medium, expansions planned, dredged)	Cornelder de Mozambique in partnership with CFM
	Nacala	14°32'40.49"S; 40°39'56.35"E	Operational	Coastal Natural (small)	CFM
	Macuse	17°53'0.44"S; 36°53'0.07"E	Planned (Aug 2023)	Coal export	
	Ibo	12°20'44.31"S; 40°34'52.15"E	Operational	Coastal Natural (very small, jetty)	
	Chinde	18°34'24.18"S; 36°27'34.41"E	Operational	River Natural (small, fishing)	
	Pemba	12°58'4.13"S; 40°29'13.35"E	Operational	Coastal Breakwater (very small)	CFM
	Mocambique	15° 1'49.34"S; 40°44'8.67"E	Operational	Coastal Natural (very small, pier)	
	Pebane	17°16'5.49"S; 38° 8'6.15"E	Operational	River Natural (small, pier)	
	Angoche	16°14'6.06"S; 39°54'2.90"E	Operational	Very small (fishing)	
	Quelimane	17°53'0.44"S; 36°53'0.07"E	Operational	River Natural (very small, agriculture export)	CFM
	Inhambane	23°52'2.32"S; 35°22'37.17"E	Operational	River Natural (small, pier)	CFM
Reunion (France)	Réunion (old)	20°56'10.50"S; 55°17'7.32"E	Operational	Coastal Breakwater (small)	
	Réunion (new)	20°55'52.65"S; 55°19'18.45"E	Operational	Coastal Breakwater (small)	
	Saint-Pierre	21°20'44.37"S; 55°28'45.15"E	Operational	Open Roadstead (very small, deep water)	
	Saint-Denis	20°53'32.42"S; 55°32'14.96"E	Operational	Open Roadstead (very small)	
Seychelles	Port Victoria	04° 38' 00.71"S; 55°28'30.28"E	Operational	Medium, commercial	Seychelles Port Authority
	Mahe	4°38'50.32"S; 55°28'56.10"E	Operational	Very small	
Somalia	Mogadishu	2° 1'40.41"N;45°20'40.59"E	Operational	Coastal Breakwater (large, commercial)	Ministry of Ports and Marine Transport (MPMT)
	Bosaso	11°17'24.81"N;49°10'53.61"E	Operational	Major port	MPMT
	Kismayo	0°23'7.75"S;42°32'39.27"E	Operational	Coastal Breakwater (very small)	MPMT
	Las Khorey	11°10'18.48"N;48°12'1.08"E	Operational	Jetties	MPMT
	Merca	1°42'43.50"N;44°46'7.62"E	Operational	Open Roadstead (very small)	MPMT
	Aluula	11°58'2.52"N;50°45'21.04"E	Operational	Small	MPMT
	Maydh	11° 0'17.98"N;47° 6'30.77"E	Operational	Small	MPMT
	Lughaya	10°41'16.99"N;43°57'1.54"E	Operational	Small	MPMT
	Eyl	7°56'13.46"N;49°51'53.10"E	Operational	Small	MPMT
	Qandala	11°28'30.11"N; 49°52'18.03"E	Operational	Small	MPMT
	Hafun	10°24'26.26"N; 51°16'9.61"E	Operational	Small	MPMT
	Hobyo	5°20'32.97"N; 48°31'54.96"E	Operational	Small	MPMT
	Garacad	6°55'37.19"N; 49°19'6.80"E	Operational	Small	MPMT
	El Maan	2°10'33.68"N; 45°35'35.68"E	Operational	Small	MPMT
South Africa	Richards Bay	28°48'1.71"S; 32° 3'16.18"E	Operational	Coastal Breakwater (Large, medium, expansions planned)	National Ports Authority (parastatal) (NPA)
	Ngqura	33°48'8.81"S; 25°41'29.05"E	Operational	?, expansions planned	NPA
	Port Elizabeth	33°57'41.61"S; 25°38'22.86"E	Operational	Coastal Breakwater (medium)	NPA
	Mossel Bay	34°10'40.69"S; 22° 8'47.60"E	Operational	Coastal Breakwater (small, limited expansions planned)	NPA
	East London	33° 1'38.73"S; 27°54'39.06"E	Operational	River Natural (small, dredged)	NPA

COUNTRY	PORT	LOCATION (COORDINATES)	STATUS	HARBOUR TYPE/CARGO/HANDLING	RESPONSIBLE AUTHORITY (where data was available)
	Durban	29°52'29.43"S; 31° 1'38.49"E	Operational	Coastal Breakwater (large, commercial, expansions planned)	NPA
	Durban deep-water port	29°58'55.55"S; 30°58'28.27"E	Proposed		NPA
	Cape Town	33°54'37.49"S; 18°25'57.32"E	Operational	Coastal Breakwater (medium, expansions planned)	NPA
	Saldanha	33° 0'27.22"S; 17°59'31.91"E	Operational	Coastal Breakwater (medium)	NPA
	Port Nolloth	29°15'25.75"S; 16°52'1.88"	Operational	Very small (Pier, Jetty, Wharf), no expansion planned	NPA
	Boegoebaai	28°44'14.71"S; 16°33'25.91"E	Proposed		NPA
	Lamberts Bay	32° 5'28.44"S; 18°18'10.94"E	Operational	Proclaimed fishing/small harbour	Depart. Public Works (DPWI) & Dept Environment (DFFE)
	Laaiplek	32°46'16.09"S; 18° 8'44.47"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	St Helena Bay	32°44'35.45"S; 18° 1'0.04"	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Saldanha Bay	33° 1'11.47"S; 17°57'3.05"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Hout Bay	34° 3'4.79"S 18°20'53.83"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Simons Town	34°11'16.37"S; 18°26'13.18"E	Operational	Coastal Breakwater (very small, naval base)	South African Navy
	Kalk Bay	34° 7'41.09"S; 18°26'59.28"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Gordons Bay Harbour	34° 9'49.97"S; 18°51'30.18"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Arniston	34°39'58.98"S; 20°13'57.29"E	Operational	Proclaimed fishing/small harbour (Slipway)	DPWI & DFFE
	Hermanus	34°26'0.52"S; 19°13'35.69"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Gansbaai	34°35'7.23"S; 19°20'36.02"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Struisbaai Harbour	34°47'58.59"S;20° 3'29.94"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Stilbaai	34°23'8.16"S; 21°25'30.51"E	Operational	Proclaimed fishing/small harbour	DPWI & DFFE
	Hondeklip Bay	30°18'58.13"S; 17°16'25.41"E	Operational	Very small, sheltered bay	
	Elands Bay	32°18'58.69"S; 18°19'11.73"E	Operational	Very small, jetty	
	Yzerfontein	33°20'46.81"S; 18° 8'58.34"E	Operational	Very small	
	Kleinbaai	34°36'58.69"S; 19°21'25.24"E	Operational	Very small, slipway	
	Witsand	34°23'49.98"S; 20°50'15.54"E	Operational	Very small, jetty	
	Knysna	34° 2'29.58"S; 23° 2'36.42"E	Operational	Very small	
	Port St Francis	34°11'2.37"S; 24°51'7.63"E	Operational	Very small	
	Port Alfred	33°35'38.30"S; 26°53'33.08"E	Operational	Very small, expansions proposed for official small harbour	
	Port St Johns	31°37'53.84"S; 29°33'9.81"E	Proposed	Proposed for official small harbour	
	Shelley Beach	30°48'30.59"S; 30°24'46.53"E	Operational	Very small, slipway, small craft	Ray Nkonyeni Local Municipality (Sonny Evans Small Craft Harbour)
	St Lucia	28°22'9.82"S; 32°24'36.29"E	Operational	Very small, jetty (estuary)	
	Kosi Bay	26°57'40.07"S; 32°49'35.85"E	Operational	Very small, jetty	Ezemvelo KZN Wildlife
Tanzania	Dar es Salaam	6°50'4"S and 39°17'57"E	Operational	Coastal Natural (medium, expansions/upgrade planned)	TPA
	Tanga	5° 3'55.04"S; 39° 6'17.07"E	Operational	Coastal Natural (small)	Tanzania Ports Authority (TPA)
	Mtwara	10°16'3.24"S; 40°11'56.43"E	Operational	Coastal Breakwater (very small)	TPA
	Mikindani	10°16'16.18"S; 40° 7'2.74"E	Operational	Coastal Natural (very small)	
	Pangani	5°25'45.93"S; 38°58'32.02"E	Operational	Very small, pier	TPA
	Kilwa Kivinje	8°44'43.70"S; 39°24'47.21"E	Operational	Open Roadstead (very small)	TPA
	Kilwa Masoko	8°56'26.89"S; 39°30'25.36"E	Operational	Very small	TPA
	Lindi	9°59'58.71"S; 39°43'8.66"E	?	Very small	TPA
	Mafia	7°54'43.08"S; 39°39'11.61"E	Jetty	Very small	TPA
	Bagamoyo	6°25'54.62"S; 38°54'23.46"E	Proposed		TPA
	Malindi (Zanzibar)	6° 9'20.28"S; 39°11'29.89"E	Operational	Coastal Natural (small)	Zanzibar Ports Corporation (ZPC)
	Mkokotoni (Zanibar)	5°52'26.70"S; 39°15'22.38"E	Operational		ZPC
	Mangapwani (green field)	5°59'31.22"S; 39°10'57.71"E	Proposed		ZPC
	Wete (Pemba)	5° 3'47.99"S; 39°43'1.88"E	Operational	Very small, jetty	ZPC
	Mkoani (Pemba)	5°21'33.14"S; 39°38'29.60"E	Operational	Very small, pier	ZPC